The George W. Woodruff
School of Mechanical Engineering

(NASA-CR-182582) LUNAR CARGO TRANSPORT VEHICLE Advanced Space Design Project (Georgia Inst. of Tech.) 76 p

N91-70306

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LUNAR CARGO TRANSPORT VEHICLE

March 1986

Georgia Institute of Technology
Atlanta, Georgia 30332

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NASA/UNIVERSITY ADVANCED SPACE DESIGN PROJECT

LUNAR CARGO TRANSPORT VEHICLE

March 1986

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NASA/UNIVERSITY ADVANCED DESIGN CONCEPTS

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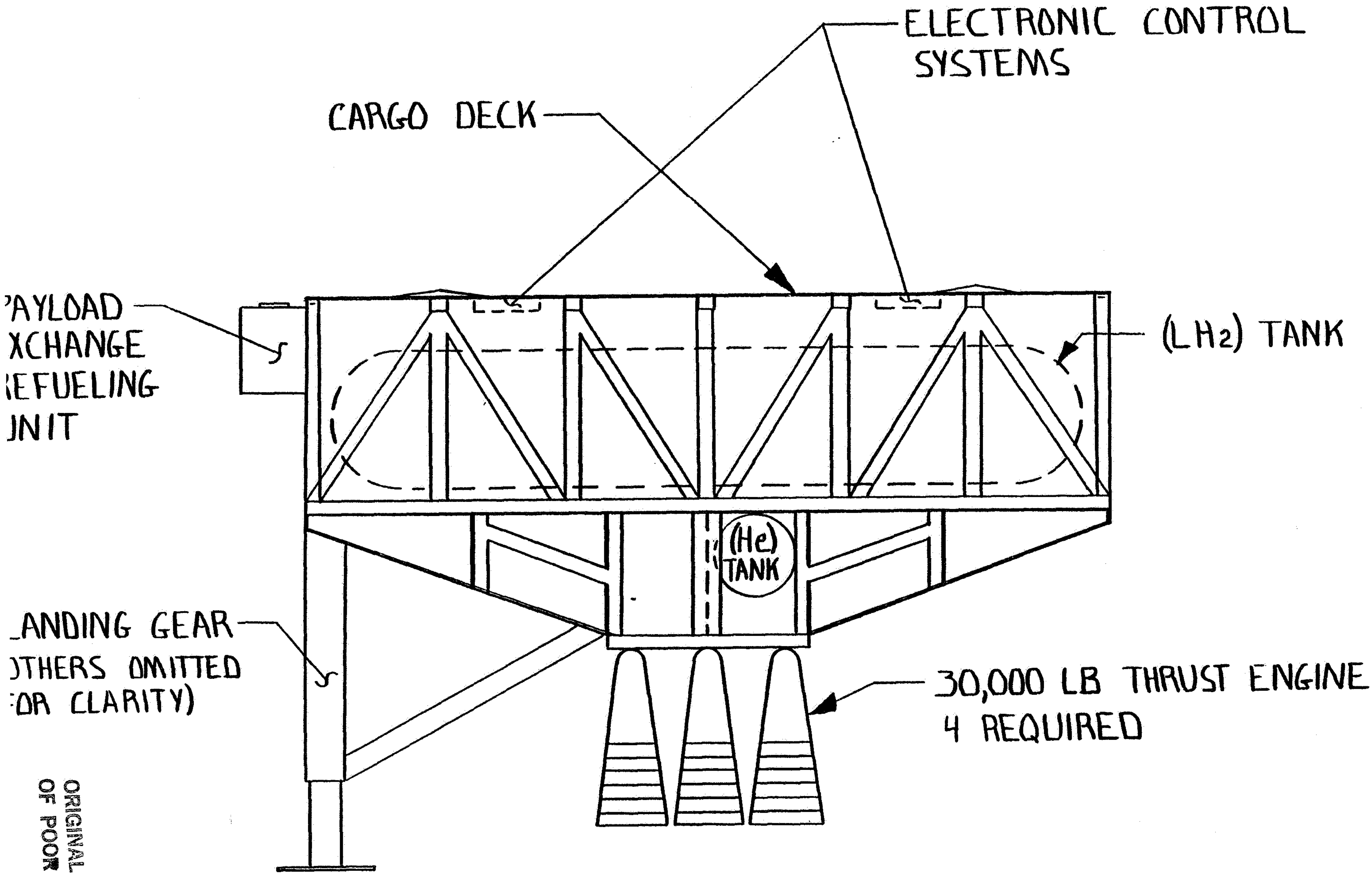
ABSTRACT

The moon is planned to be used as a mining base. As a part to shuttle mined materials, mining equipment and base personel between the earth and the moon, a transport system between the lunar surface and lunar orbit must be developed.

The Lunar Cargo Transport Vehicle (LCTV) must comply with some performance objectives. The LCTV must be able to reach lunar orbit with a payload of 65,000 lbs (2948.4 kg) while minimizing the fuel consumption. While in orbit, the LCTV must rendezvous with the Orbital Transport Vehicle (OTV), with minimal docking maneuvers by the OTV. The LCTV's capacity should also include missions between different locations on the moon. The LCTV must perform all of these functions while being automatically controled.

There are some constraints that limit the design of the LCTV. The cargo should not exceed space shuttle capacity. The amount of service time between missions should be minimized. Because of time restictions on this project, the use of existing technology is important. Finaly, the landing area must be a flat, stable area with minimal dust thickness and at least one square acre.



LCTV

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STRUCTURES FOR THE LCTV

INTRODUCTION

The mission of the Lunar Cargo Transfer Vehicle (LCTV) is to transport a maximum of 65,000 lbs. mass of cargo into lunar orbit from the lunar surface and then to transfer an equal amount from orbit back down to the lunar surface. The structure is the portion of the vehicle which supports all of the systems which allow that vehicle to carry out that mission. The structure is broken down into the following groups:

1. Engine mounting deck.
2. Main structural supports and dust and debris shield.
3. Fuel tank deck.
4. Cargo deck structure.

ENGINE MOUNTING DECK

According to the propulsion engineer, only one plane of rotation was necessary for the engine gimble mechanisms. Therefore, decided to use a rather standard pin and socket type gimbling mechanism. The mechanism is made of stainless steel and the socket is coated with teflon for friction reduction.

The main engine mounting deck will be machined from 7075 aluminum and will include machined ribs located to distribute stresses throughout the 15 ft. by 15 ft. (4.57 m. by 4.57 m.) area (see fig. 1-001). Flat areas will be left for the gimbling mechanisms to fasten to and the top will have flat areas to accomodate the next stuctural level. Hydraulic cylinders will be attached on both sides of each engine and to the main engine deck to provide gimbling action of the engines.

MAIN SUPPORTS AND DEBRIS SHIELD

Several different types of main structure were investigated. A system of I or T structural shaped beams was tested. In the design, the relationship between the angle of the beams ascent to higher decks and the resulting beam loads resulted in many iterations. A satisfactory design was not arrived upon. The results were either too weight inefficient, too volumetrically inefficient, or both.

Considered a system of trusses. The problems encountered with a truss network include the large amount of fasteners needed (adding weight) and the complicated joints that result. Welded joints would appear to offer a solution, however, high quality aircraft aluminum has low weld reliability and weight penalties can ensue again.

Finally arrived on a system of large machined panels. Using a finite element analysis package, a panel exhibiting maximum resistance to stress and minimum mass could be designed. These panels were machined out of 7075 aluminum. Developed a panel configuration that transfers all of the moments through the center of gravity of the ship (see fig. 1-101 thru 1-104). It is also layed out in such a way as to allow the panel thicknesses to vary depending on the results of the finite element analysis without causing intereference to introduced. These panels distribute the force from the main engine mounting deck to 60 ft. by 35 ft. (18.29 m. by 10.67 m.) upper decks. I-beams were added around the perimeter of the panel configuration and four I-beams were placed across the width of the ship at 10 ft. (3.05 m.) intervals. There was no beam added in the center position as a structural panel already carries that load. These beams were added to help distribute the load of the fuel tanks on the next deck. The main support panels are notched to secure these I-beams flush with the rest of the structural panels top surface.

Fastened to the top surface of the main support panels is a 1/2 in. (12.7 mm.) thick aluminum plate. The purpose of this plate is to protect the next deck from flying dust and debris that will result from takeoff and landing thrust.

FUEL TANK DECK

There are three fuel tanks. Two liquid hydrogen (LH2)tanks and one liquid oxygen (LO2) tank. The hydrogen tanks are 11 ft. (3.35 m.) in Dia. and 56.30 ft. (17.16 m.) long. The oxygen tank is 9.00 ft. (2.74 m.) in Dia. and 51.70 ft. (15.76 m.) long. The tanks are oriented lengthwise and parallel to one another. The two hydrogen tanks are placed on the out side of the tank deck. This is done so that as the hydrogen is used up faster than the oxygen, the center of gravity of the ship remains the same. The sum of the diameters of the tanks is 31.00 ft. (9.45 m.). The tank deck is 35.00 ft. (10.67 m.) wide. Therefore, the tanks are positioned with a 1 ft. (.30 m.) gap between the (LH2) and (LO2) and a 1 ft. (.30 m.) gap between the (LH2) and the edge of the ship.

The three fuel tanks will be mounted to the the main strucural supports through the aluminum debris plate. The mounts that attach to the fuel tanks are discussed in the fuel tank section of the report. The extra space between the fuel tanks will be used to house the piping and pumps needed to supply the engines with fuel. The space will also be used to house the central electronic control systems. In this location the system will be protected from solar radiation, dust and debris, and will be cooled by the liquid fuel tanks. These systems operate at peak efficiency when cold. They will also be located in a way to allow them to be easily accessed for repairs.

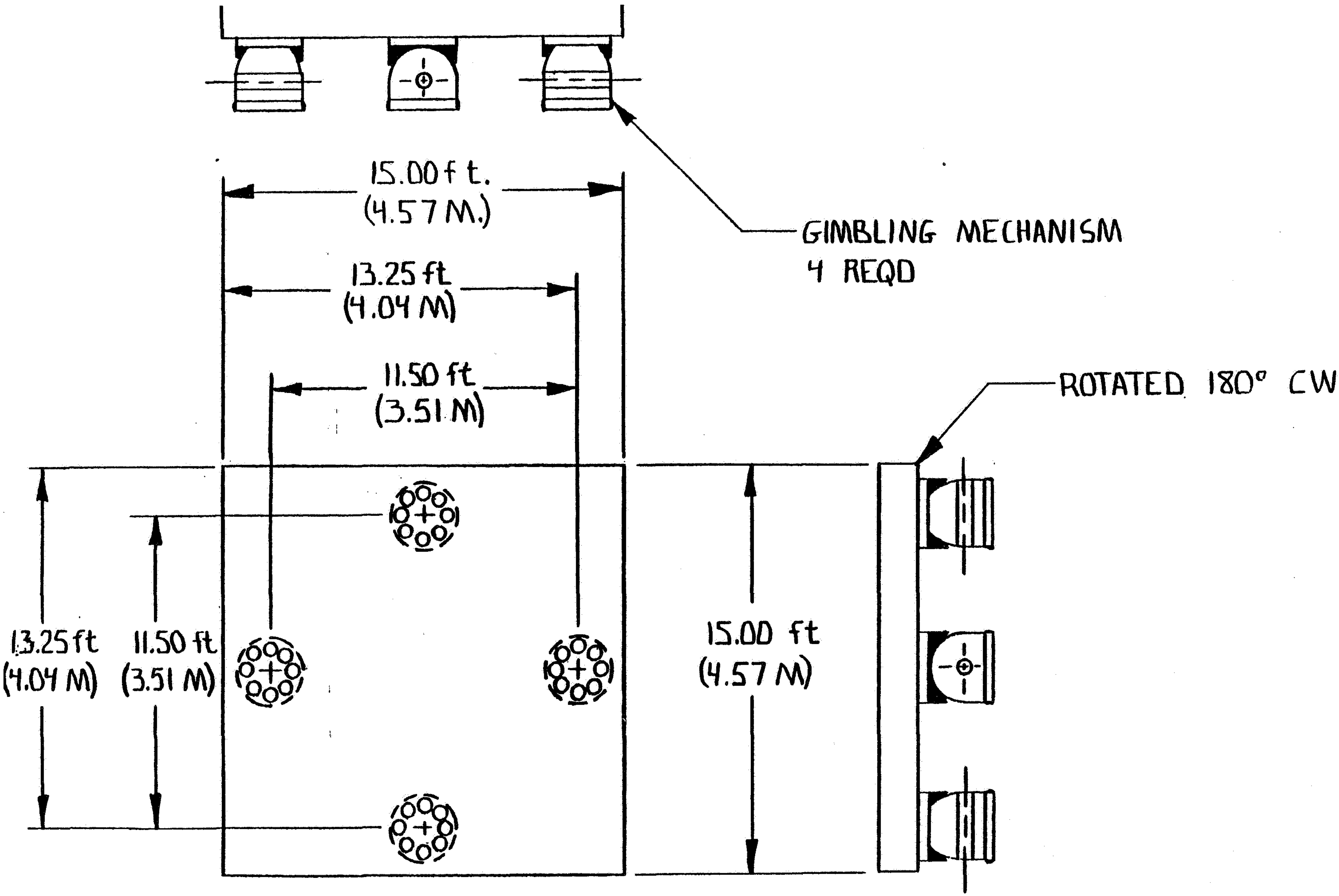
The structure to support the next deck will consist of machined 7075 aluminum panels that rise vertically around the perimeter of the ship and in the two gaps between the tanks (see fig. 1-201 through 1-203). Five I-beams will run across the width of the ship at 10 ft. (3.05 m.) intervals and will fit into notches in the panels for a flush top surface. A 1/2 in. (12.7 mm.) thick aluminum plate will be added to the top of this surface to protect the lower deck from contamination. There will be doors added in key locations for access. This will be the surface of the cargo deck.

CARGO DECK

On the cargo deck will rest the cargo pallet. Any cargo to be transported will be fixed to this pallet. The main concern of this deck is that of attaching the pallet to the ship. The maximum mass of the cargo and pallet is 65,000 lbm. (29,483.5 kg.). The pallet will be lowered onto the ship by a crane which is assumed to be part of the lunar base equipment.

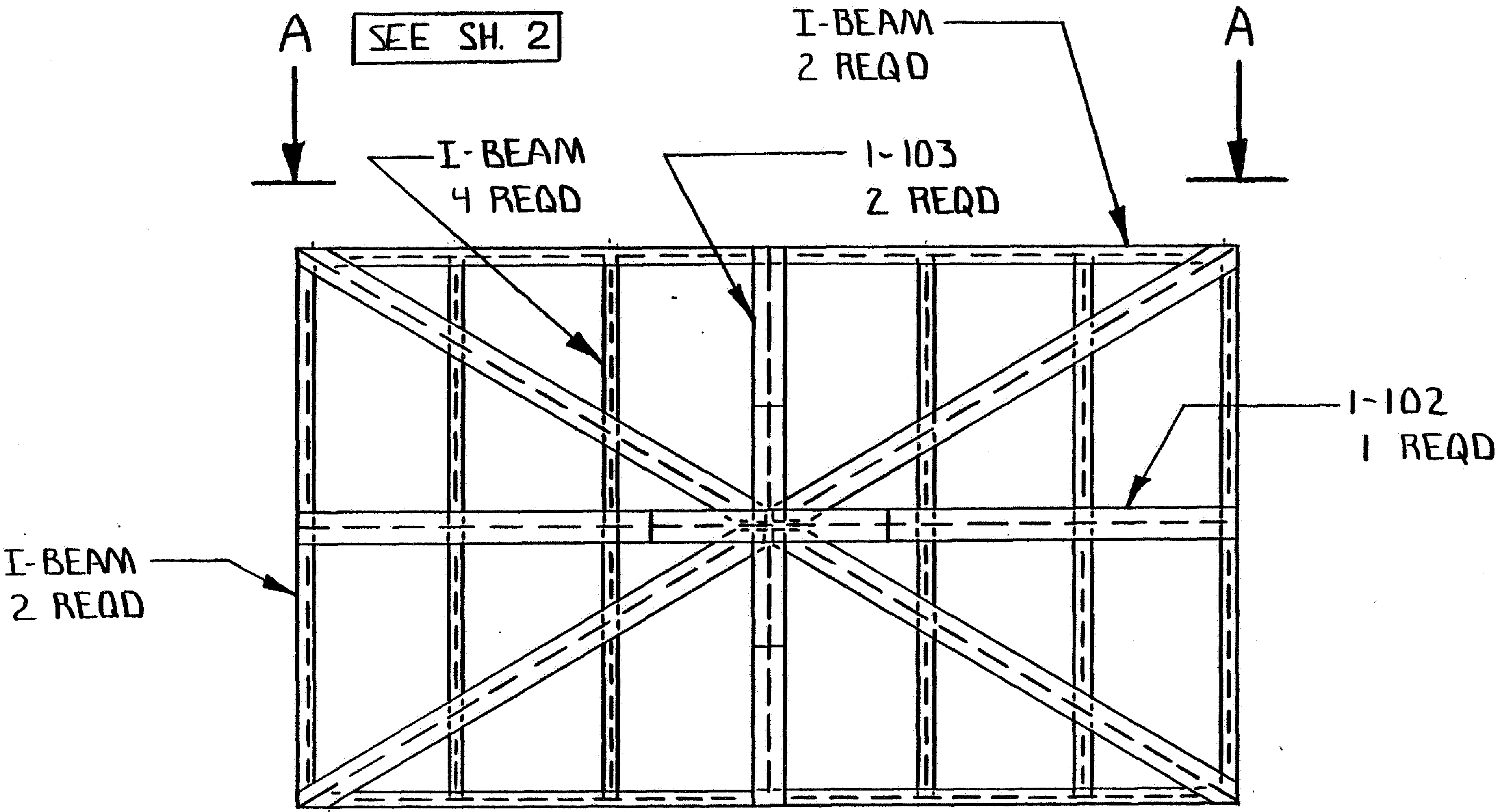
Two pyramid shaped cones will protrude from the cargo deck at either end of the ship(see fig. 1-301). These pyramids will mate with two female pyramidal cones on the bottom of the pallet. These cones will allow the pallet to be aligned properly as it is lowered onto the ship. The pallet will then be locked into position by six hydraulic linear actuators. The cylinders will be moun o the beams of the fuel tank deck with three on each side of pallet.

The ren er of the cargo deck will be used to house the various power , hydraulic pumps, electric motors, and control rocket tanks ed to control and power the ships systems. These system ll be shielded as necessary to protect them from solar radiat and external impact.



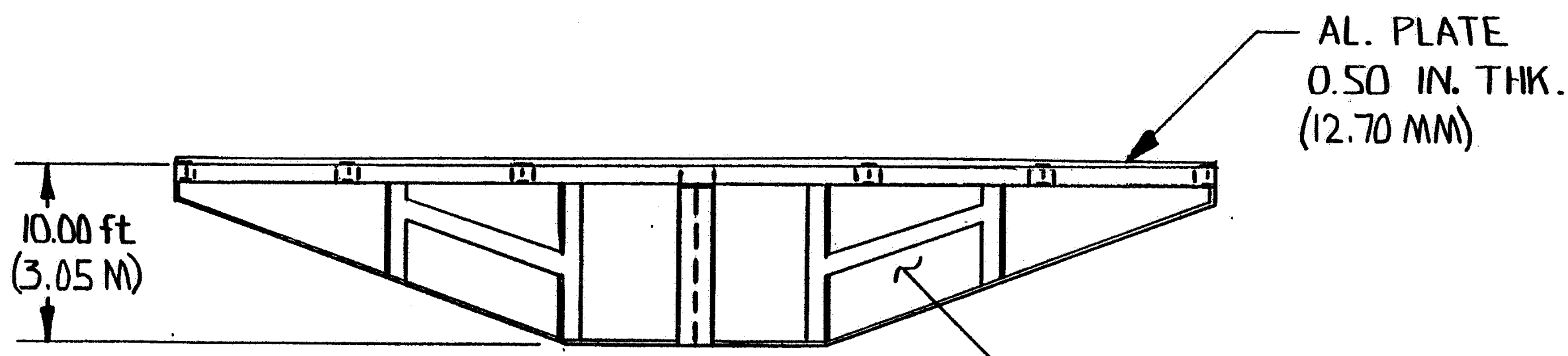
15.00 ft.
(4.57 M.)
13.25 ft
(4.04 M)
11.50 ft
(3.51 M)
GIMBLING MECHANISM
4 REQD
ROTATED 180° CW
13.25 ft
(4.04 M)
11.50 ft
(3.51 M)
15.00 ft
(4.57 M)

FIGURE 1-001



BOTTOM VIEW

FIGURE 1-101



VIEW A-A

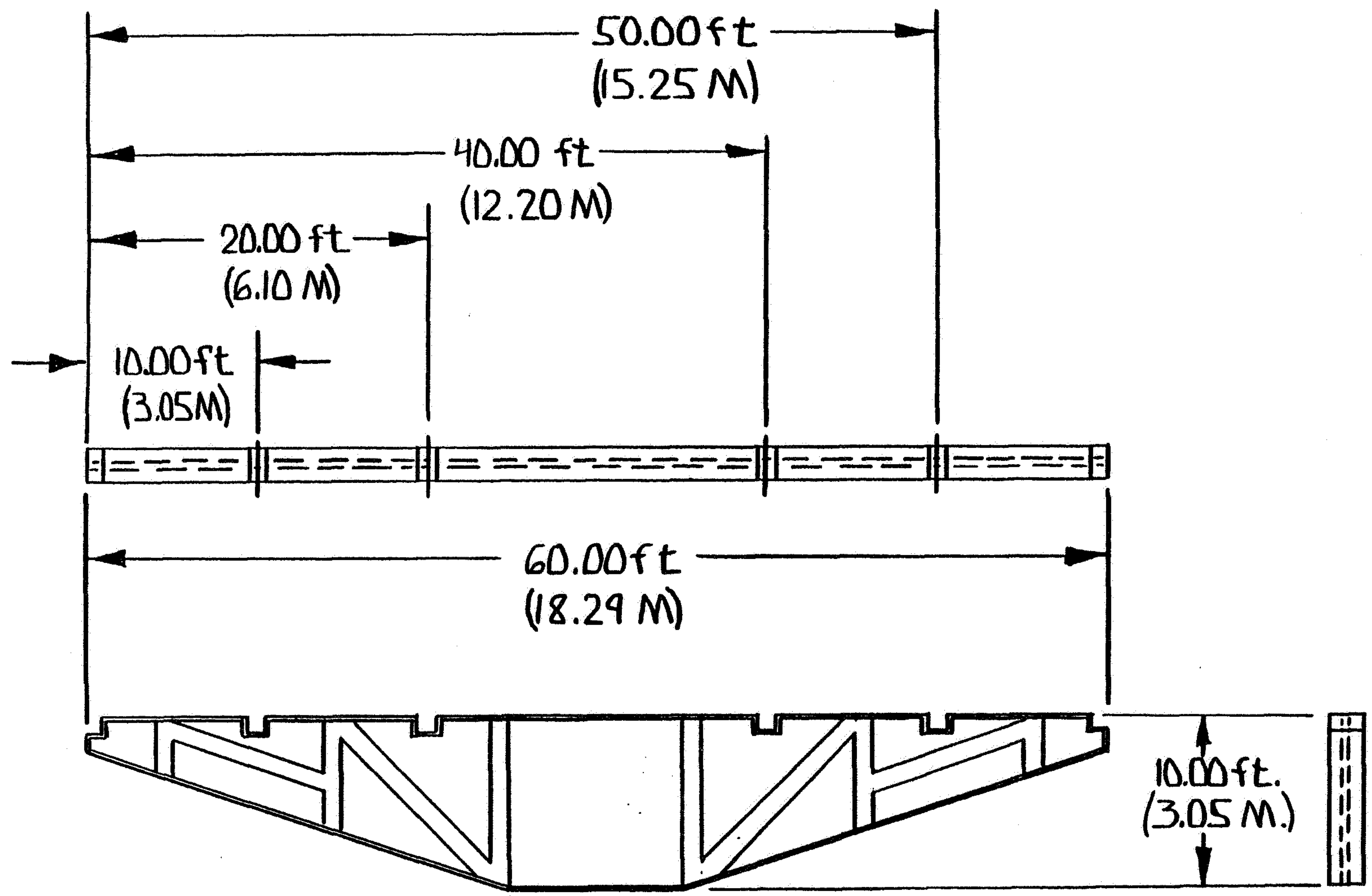

50.00 ft
(15.25 M)
40.00 ft
(12.20 M)
20.00 ft
(6.10 M)
10.00 ft
(3.05M)
60.00 ft
(18.29 M)
10.00 ft.
(3.05 M.)

FIGURE 1-102

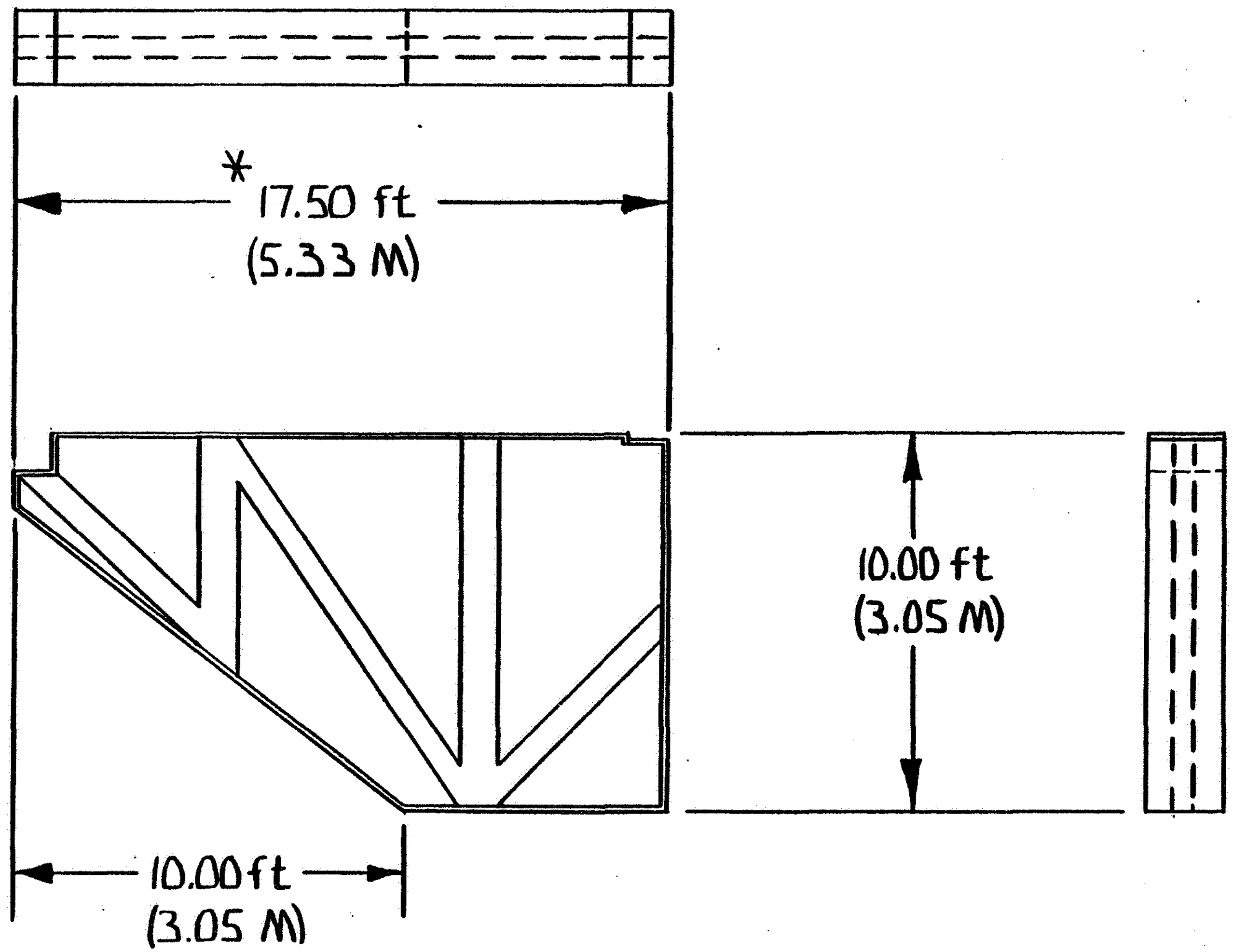


FIGURE 1-103

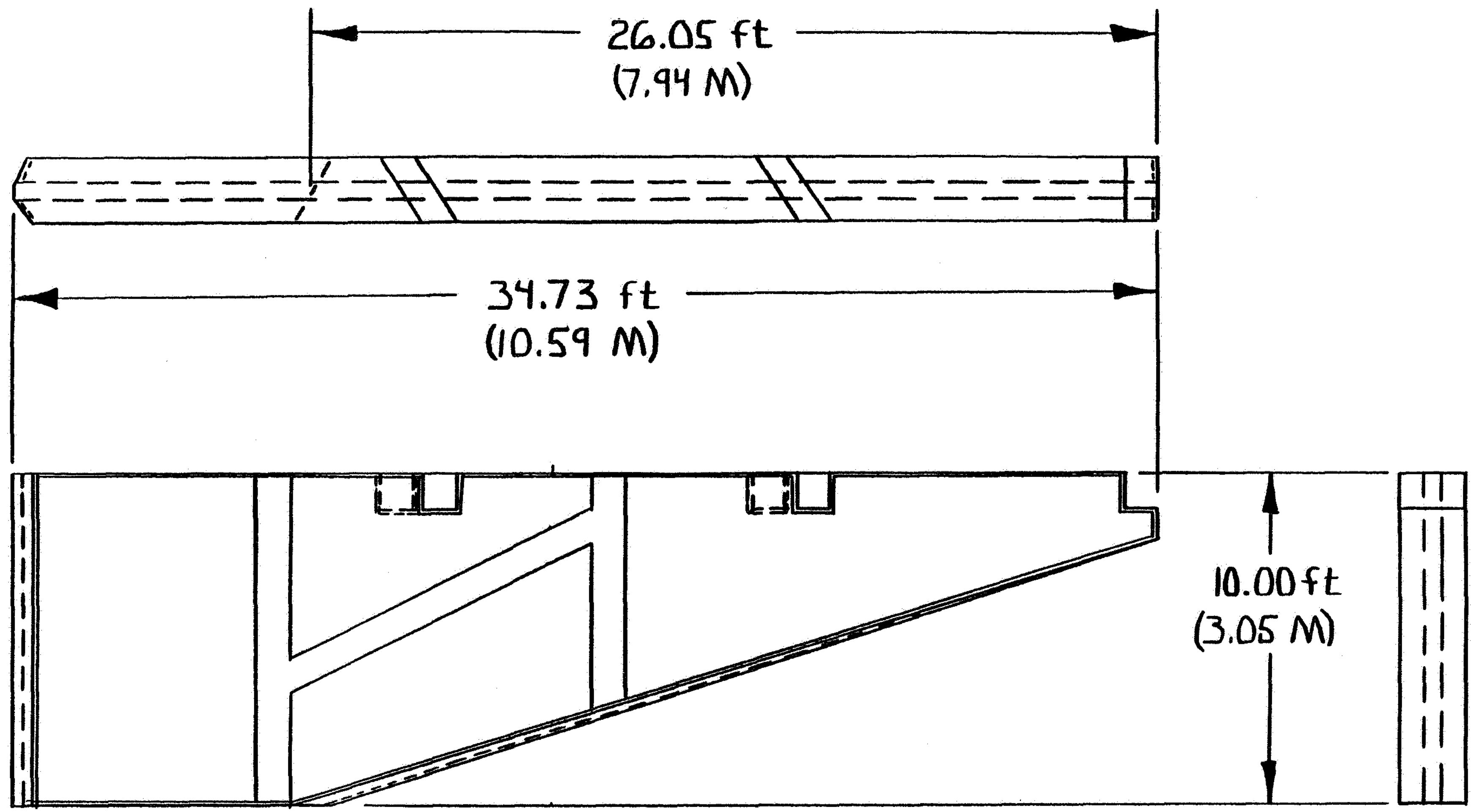
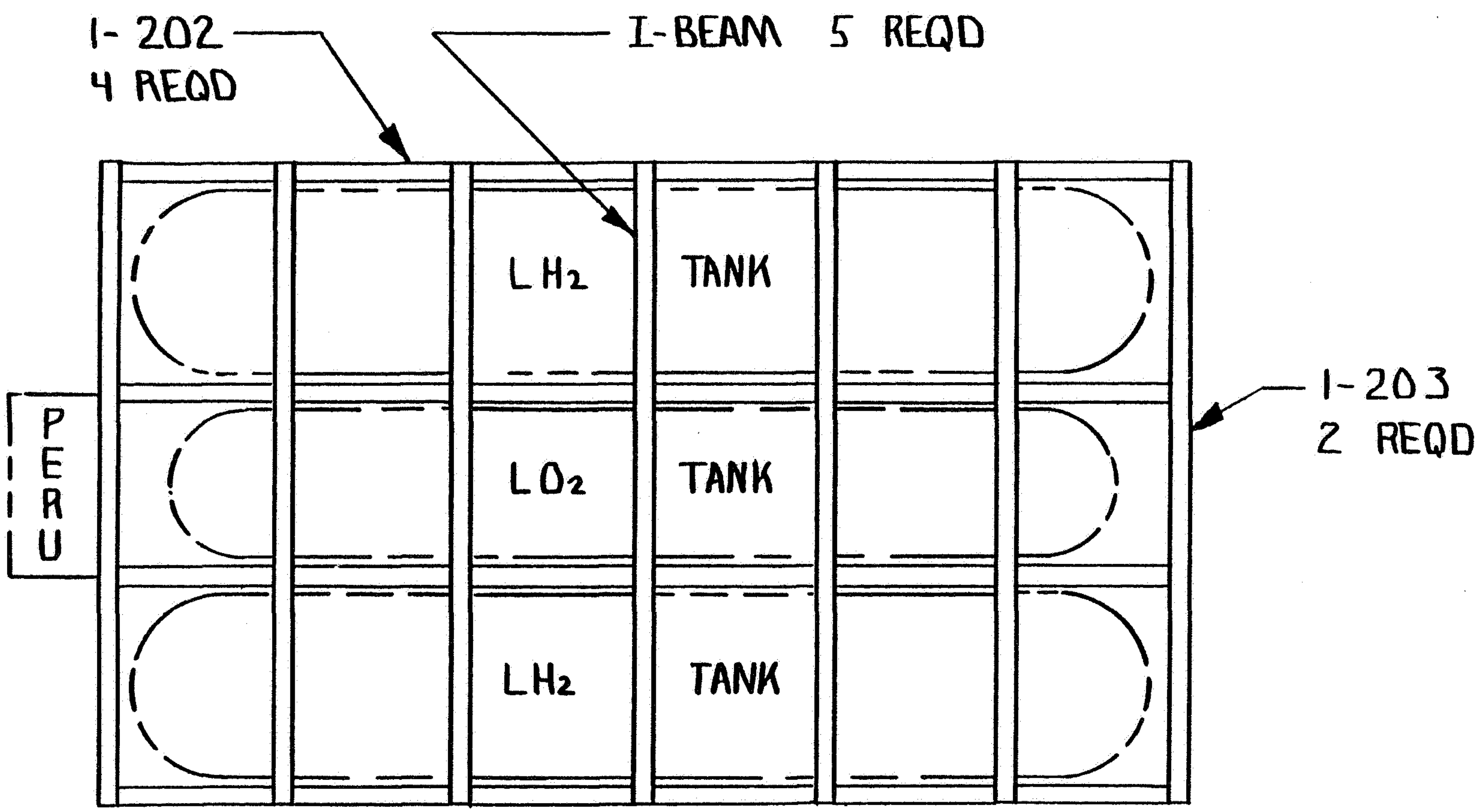


FIGURE 1-104



1- 202
4 REQD
I-BEAM 5 REQD
1-203
2 REQD
LH2 TANK
LO2 TANK
LH2 TANK
PERU

FIGURE 1-201

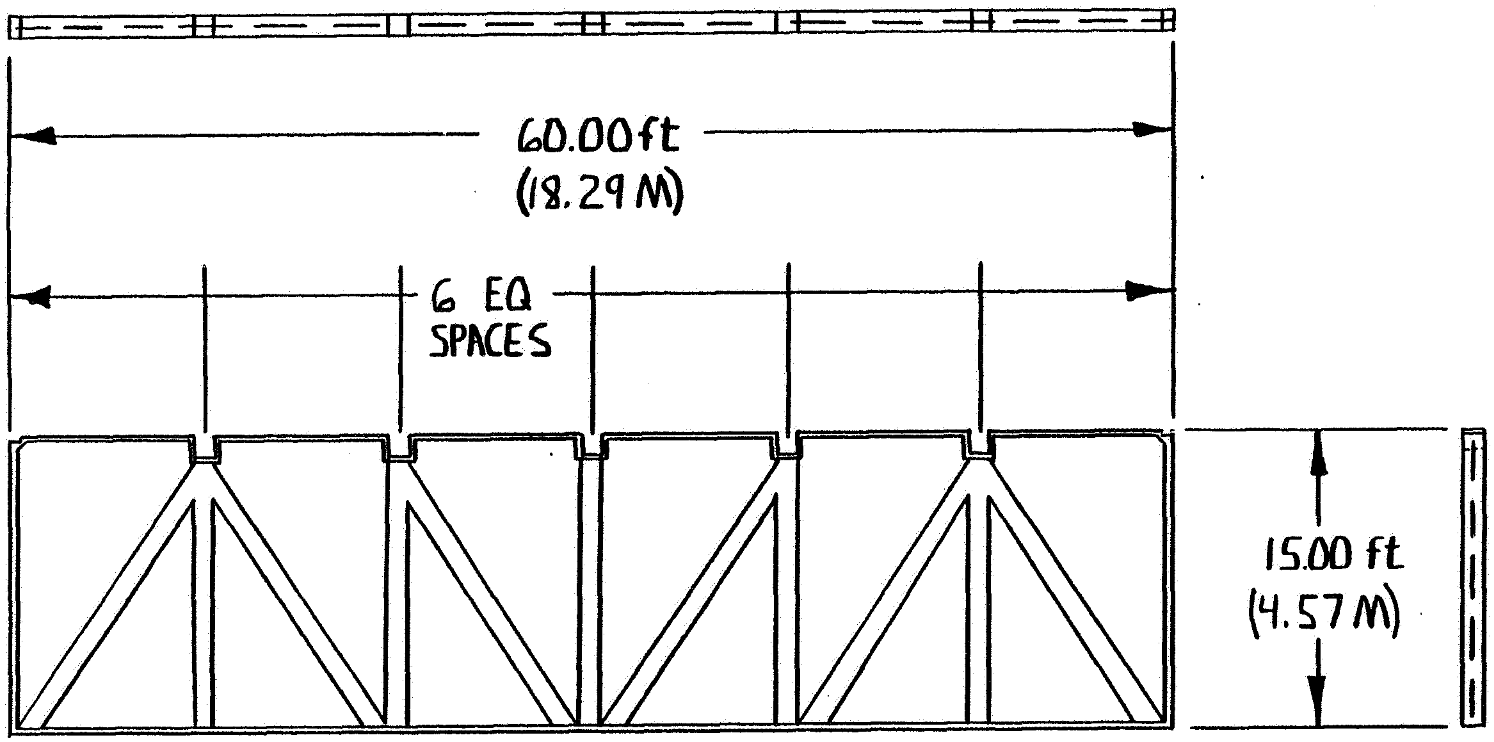


FIGURE 1-202

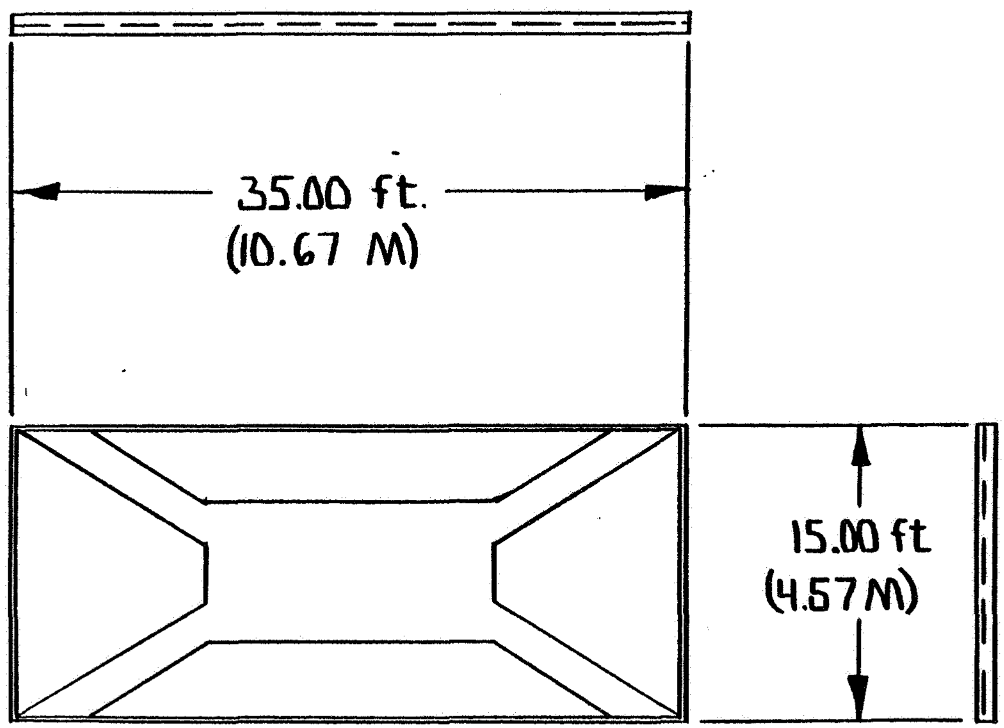
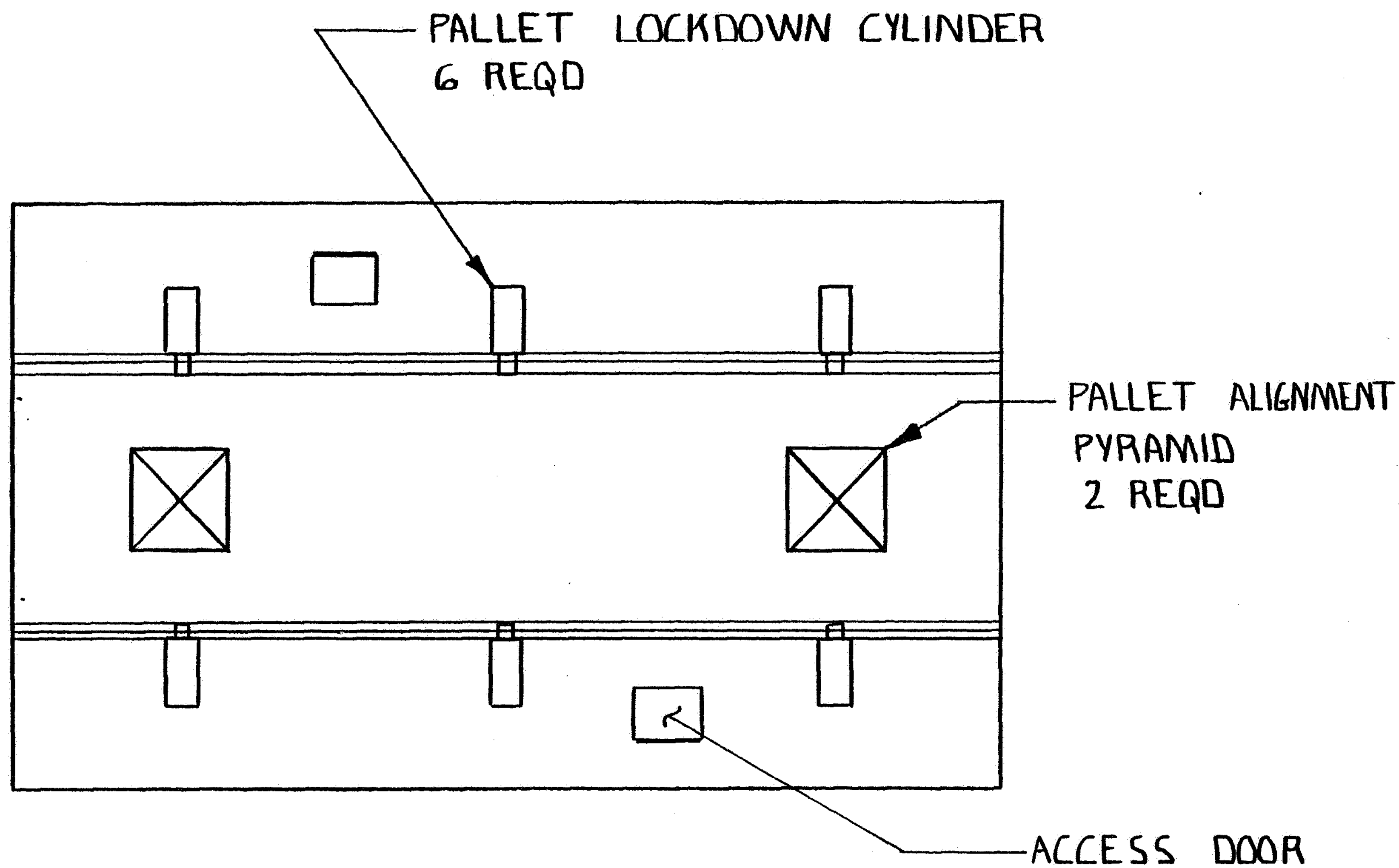


FIGURE 1-203



CARGO DECK

FIGURE 1-301

SPACECRAFT PROPULSION AND POWER SYSTEMS

Mission requirements for the Lunar Cargo Transport Vehicle (LCTV) require a propulsion system that can place the specified payload in a lunar orbit and and allow the spacecraft to rendevouz with the Orbital Transfer Vehicle (OTV). Additionally, the transporter must be able to return to its original launch point. This engine system must also allow multiple, rapid turn around flights. Finally, design and economic considerations stress the use of fuel system agents that can be obtained on the lunar surface.

Main Propulsion System (MPS)

A survey of all existing technology leads to several basic forms of propulsion. The most promising methods are nuclear rockets, thermoelectric rockets, and liquid chemical rockets.[8] All these propulsion systems have their positive and negative points. The nuclear rocket provides good thrust characteristics, low fuel consumption, and the requisite acceleration abilities. The nuclear sytem is not deemed practical, though, due to radiation problems and the extremely complicated control system that does not integrate well with the LCTV's proposed control system. The thermoelectric rocket, also known as the ion rocket or the MPD thruster, has low fuel consumption and long system life. Unfortunately this rocket does not provide high enough acceleration or thrust level to be used to boost a spacecraft off the lunar surface. Many of the practical fuels, such as mercury and cesium, are extremely toxic, also.

The final form of propulsion under examination, the liquid chemical rocket, is deemed the most practical and useable system. The chemical rocket can provide high thrust and acceleration levels, restartabilty, proven control systems, and decades of proven usefullness in space applications. Primarily, the problems exist in areas of high fuel consumption and explosive fuel mixtures. It is felt that the positive aspects of this system far out weigh the negatives. Additionally, it is felt that the existence of several liquid rocket manufacturers and the depth of the associated rocket technology will provide good economic and safety benefits.

At the present time, only one engine is being manufactered and used that falls in the required thrust range and allows multimission use. This engine, the RL10A-3-3A, is used in the Space Shuttle upper stage cryogenic sytem. Under development for the Space Shuttle program by Pratt & Whitney Aircraft Division is the "Advanced Expander Cycle Engine".[4] This engine is proposed to be used in the Space Shuttle and an Earth orbital vehicle. Both these engines provide thrust levels in the 15,000 lbf. (66,750 N) range.

The LCTV Flight Simulation Computer Program was used to examine application of various arrangements of these two engines types to be used as the propulsive system of the LCTV (see the Computer Usage section). Arrangements of over four engines were ruled out due to dynamic and control difficulties. When simulated with four or less engines, the LCTV could not reach orbital velocities and return to the surface with realistic burn times or fuel consumption levels. This mandates that a new engine must be developed to power the spacecraft.

Again, the simulator was used to determine the proper engine thrust level using theoretical fuel consumption levels. Final analysis of the spacecraft system resulted in the choice of four 30,000 lbf. (133,500 N) engines based on the Advanced Expander Cycle Engine technology. It should be noted that a primary consideration in final engine sizing was giving the LCTV the ability to fly under a multiple engine failure condition. Using this engine arrangement, the spacecraft is able to make orbit or return to the surface, depending upon the altitude, with two opposing engines not functioning.

Fuels under consideration were only those that could use oxygen as the oxidizing agent. This is because oxygen is believed to available to be mined in sufficent quantities from the moon. RP-1, a form of kerosene, and liquid hydrogen are two fuels most commonly used with oxygen. RP-1 presents problems for multimission use. This is due to nozzle deterioration problems. Thus, most of such research has been directed toward liquid hydrogen, as is used in the Advanced Expander Cycle Engine. Thus, the hypothetical LCTV engine will use the liquid hydrogen-liquid oxygen combination.

The engine system is divided into two groups of two opposing engines (see Dwg. 2-002). These each have their own fuel line set and an individual oxidizer line set that splits at the LOX tank. The dual loop system is connected in parallel in order to provide fuel to the opposite engine group (see Dwg. 2-001) in the event of system failure. All regulating and cutoff valve assemblies will be double valve systems to assure positive, redundant system shut off. These valve assemblies are all designated to fail in a closed position.

The four engine arrangement and the control requirements indicated that the MPS attitude control system could be designed allowing each engine group to gimbal along one axis. The gimbal system is proposed to be operated by using two hydraulically operated piston on each rocket (see Engine System Schematic). As one cylinder extends, valving will allow the opposite cylinder to retract the required amount. This arrangement will provide strong motor positioning.

Reaction Control System (RCS)

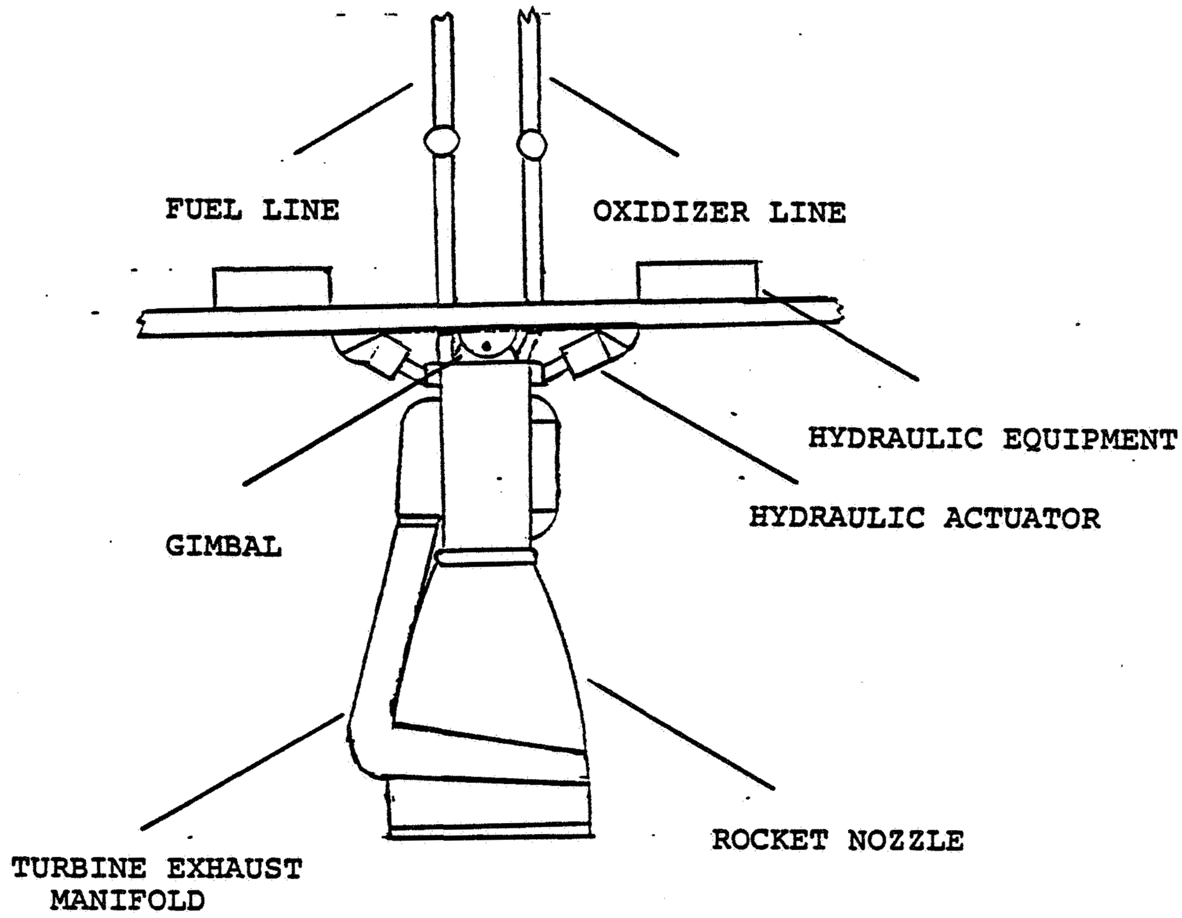
Docking and payload transfer require finely tuned flight

MAIN PROPULSION SYSTEM SPECIFICATIONS

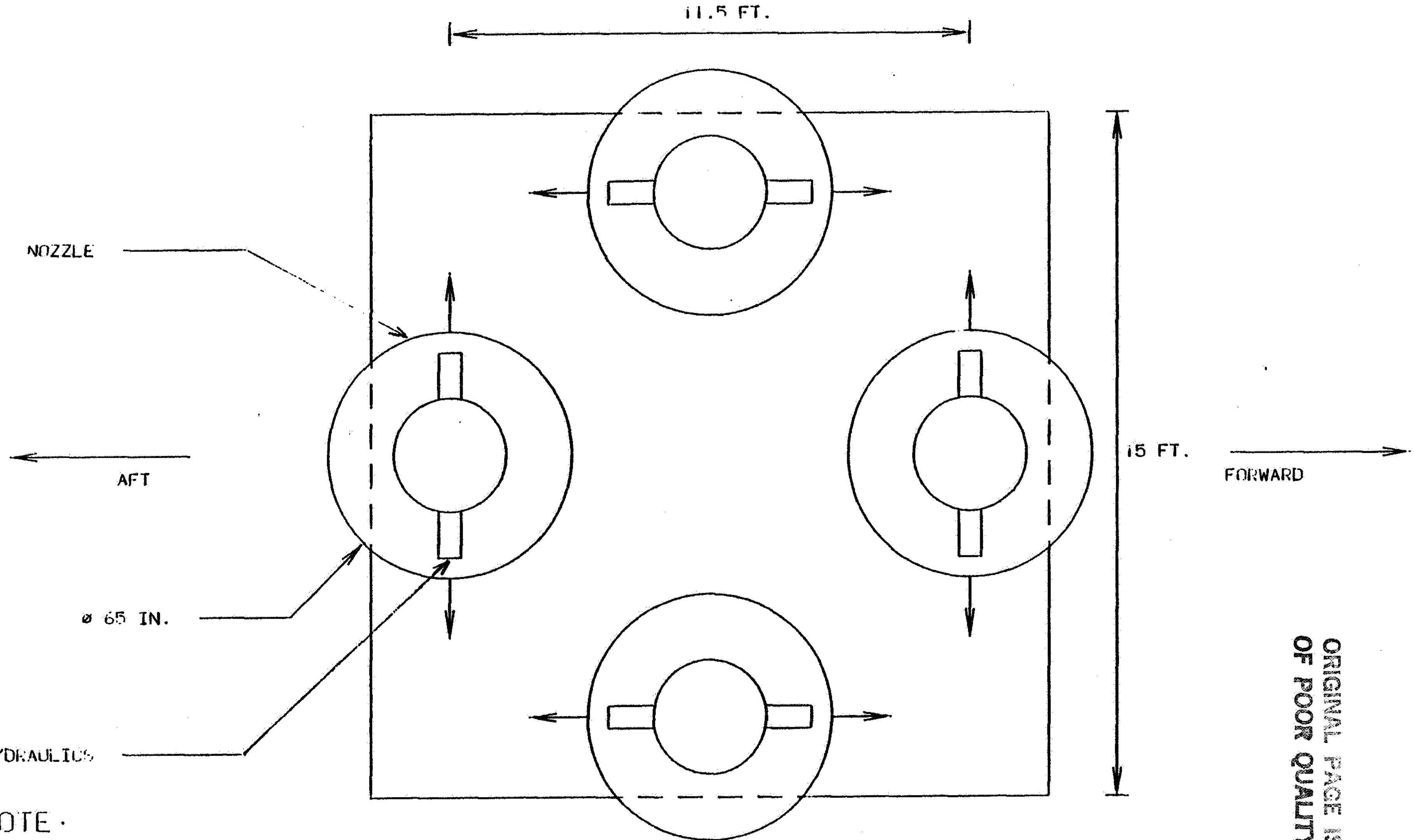
Total Number of Engines: 4
Thrust Per Engine: 30,000 lbf. (133,500 N)
Total Thrust: 120,000 lbf. (534,000 N)
Thrust Range: 0% to 25% and 100%
Engine Weight: 800 lbm. (362.88 kg.)
Nozzle Max. Diameter: 65 in. (1.651 m)
Total Engine Length: 150 in. (3.81 m)
Fuel: Liquid Hydrogen
Oxidizer: Liquid Oxygen
Mixture Ratio (O/F): 5 to 1
Fuel Consumption: 11.3 lbm./sec (5.1257 kg./sec)
Oxidizer Consumption: 56.66 lbm./sec (25.701 kg./sec)

REACTION CONTROL SYSTEM SPECIFICATIONS

Number of RCS Pods: 4
Number of Primary Thrusters Per Pod: 3
Number of Vernier Thrusters Per Pod: 6
Thrust Per Primary Thruster: 870 lbf. (3,871.5 N)
Thrust Per Vernier Thruster: 24 lbf. (106.8 N)
Fuel: Monomethylhydrazine
Oxidizer: Nitrogen Hydroxide
Mixture Ratio (O/F): 1.57
Max. Yaw Acceleration: .3360 rad/sq. sec
Min. Yaw Acceleration: .1680 rad/sq. sec
Max. Pitch Acceleration: .8084 rad/sq. sec
Min. Pitch Acceleration: .4042 rad/sq. sec
Max. Roll Acceleration: .4032 rad/sq. sec
Min Roll Acceleration: .2016 rad/sq. sec
Max. Translation Acceleration: .7308 ft./sq. sec (.2226 m/sq. sec)
Min. Translation Acceleration: .3654 ft./sq. sec (.1114 m/sq. sec)
Lateral Acceleration: .01034 ft./sq. sec (.003152 m/sq. sec)



MPS ENGINE SYSTEM SCHEMATIC
2-001



NOTE ·
THE ARROWS ON THE ROCKETS
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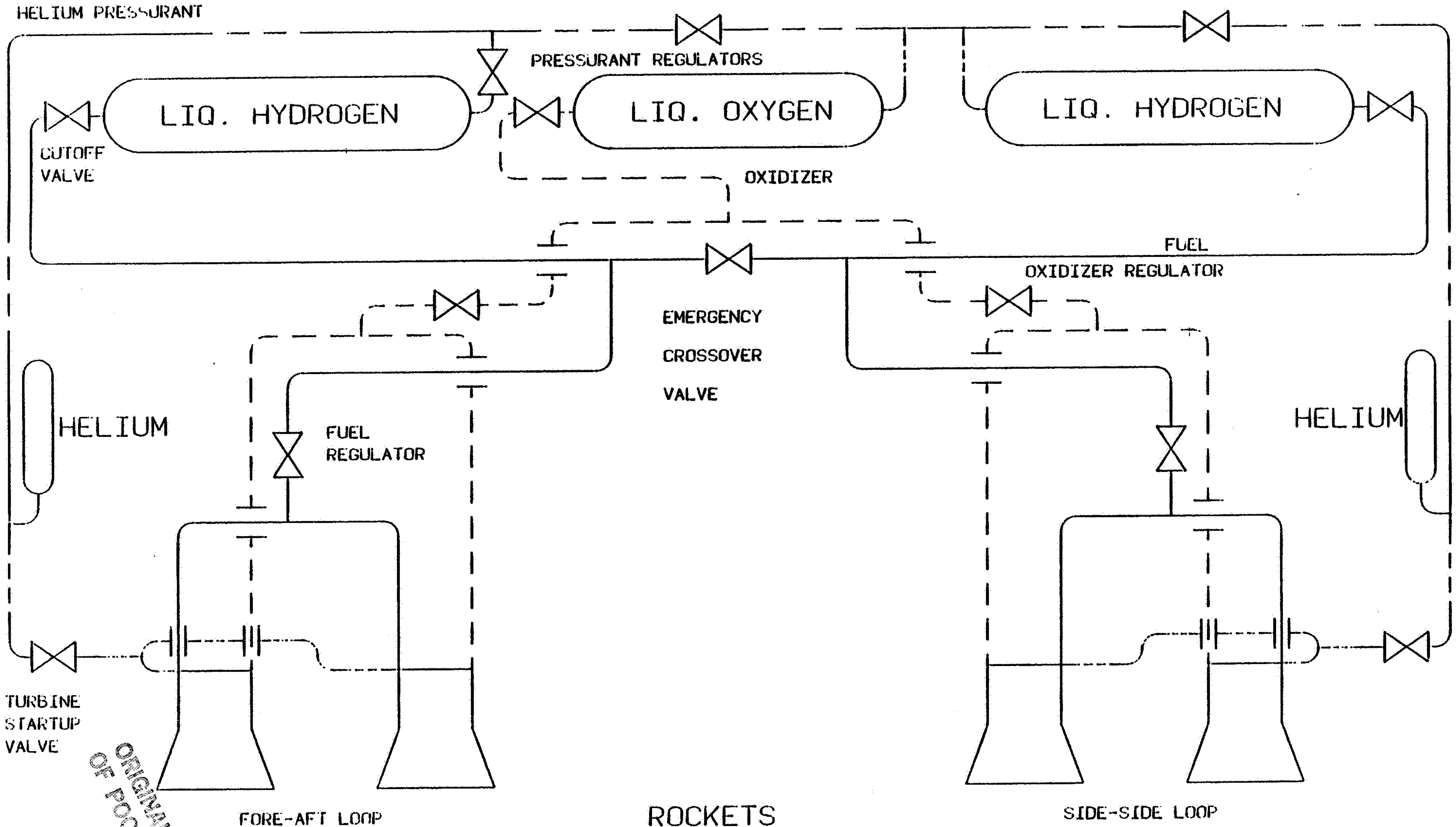

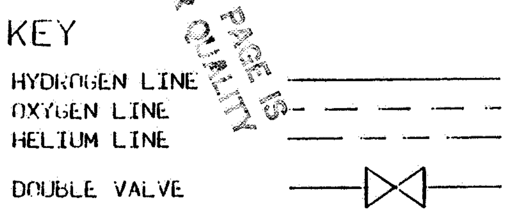

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TITLE: MPS PIPE SCHEMATIC

DESIGN: TJ DATE 3-5-86

CHECK: D.D.B DATE 3-6-86

DRWG NO.2-003

FUEL SYSTEM TANKS

The fuel system tanks will need to meet the following requirements:

Main Propulsion System (MPS)

Fuel: Liquid Hydrogen [7]
Amount: 34000 lb. (15,426 kg.)
Freezing temperature: -435 F (-259 C)
Boiling temperature: -423 F (-253 C)
Density at b.p.: 4.43 lbm/cu. ft. (71 kg/cu. m.)
Materials compatability: Stainless steel,nickel alloy
Aluminum alloys, Kel-F

Oxidizer: Liquid Oxygen
Amount: 170,000 lb. (77,132 kg.) [7]
Freezing temperature: -362 F (-219 C)
Boiling temperature: -294 F (-181 C)
Density at b.p.: 71.29 lbm/cu. ft. (1142 kg/cu. m.)
Materials compatability: Stainless steel, nickel alloy,
copper, aluminum, Teflon, Kel-F

Reaction Control System (RCS)
Note: Two RCS fuel systems are required; one for the forward RCS and one for the aft RCS. [15]

Fuel: Monomethylhydrazine (MMH) CH2NH-NH2 [7]
Amount: 900 lb. (408 kg.)
Freezing temperature: -63 F (-53 C)
Boiling temperature: 187 F (86 C)
Density at 68 F (20 C): 54.8 lbm/cu. ft. (878 kg/cu. m.)
Materials Compatability: Aluminum, stainless steel, Teflon,
Kel-F, polyethylene

Oxidizer: Nitrogen tetroxide N2O4 [7]
Amount: 1415 lb. (642 kg.)
Freezing temperature: 11 F (-12 C)
Boiling temperature: 70 F (21 C)
Density at 68 F (20 C): 89.9 lbm/cu. ft. (1440 kg/cu. m.)
Materials Compatability: Aluminum, stainless steel, Teflon,
nickel alloys

Pressurant for the MPS and the RCS: Helium
Pressure capability: 4000 psig (27,500 kPa)
Volume: 14,000 cubic feet at 50 psi (400 cu. m. at 345 kPa)

Dimensions of Tanks

The tanks are to be placed on a deck, the width and length as determined by the payload deck and the height as determined by the diameter of the largest tank plus the plumbing plus an access clearance. The most space and weight efficient method is to place each fuel in a separate spherical tank. This method also offers a constant center of gravity independant of the amount of fuel left in each tank. Since the structural design of the LCTV does not allow such a configuration, large diameter cylindrical tanks will be used for the MPS fuel and oxidizer, with smaller spherical tanks used for the RCS fuel and oxidizer, and the Helium.

With an expulsion device volume of 15%, an ullage volume of 5% and an expulsion efficiency of 97% the volumes are: Hydrogen 10,000 cu. ft. (283 cu. m.), Oxygen 3100 cu. ft. (88 cu. m.). In trying to keep the deck area as close to 30 X 60 ft. (9.1 X 18.2 m.) as possible a configuration of two hydrogen and one oxygen tank will be used. All of these tanks will use spherical ends and uniform cylinders. After area and weight optimization the following values are found for each tank: (Note 2 hydrogen tanks)

	Oxygen		Hydrogen	
	ft.	(m)	ft.	(m)
Cylinder length:	42.7	(13.0)	45.3	(13.8)
Radius:	4.50	(1.37)	5.50	(1.68)
Total length:	51.7	(15.8)	56.3	(17.2)

The helium will be used as a pressurant to expell the fuels for both the RCS and the MPS. This will require a total of 14,000 cubic feet at 50 psi (400 cubic meters at 345 kPa). The helium will be stored at 2000 psi (13,800 kPa) in two tanks of 175 cubic feet (5 cubic meters) each. This will require a diameter of 7 feet (2.1 meters) for each tank.

The fuel tanks for the RCS will be those already in use on the Space Shuttle. Since these are the correct volumes and fuels for our vehicle, there is no need to design new tanks when these are already proven. See [15] for exact specifications.

Fuel Expulsion From Main Tanks

There are two methods of fuel expulsion: Impulse Settling and Positive Expulsion.

The Impulse Settling method [7] employs a small propulsive force directed axially, parallel to the vehicle centerline of thrust. This acceleration forces the propellant to cover the tank outlet prior to initiation of main engine operation. Although this method would eliminate the need for positive expulsion devices for the main propellant tanks, it would necessitate separate positive-expulsion propellant tanks for the sole use of the reaction control system. The disadvantages of this impulse-settling method are (1) no control of the vehicle center-of-gravity shifts, and (2) low thrust-to-weight ratio under these conditions, which may increase response times beyond tolerable limits.

The Positive Expulsion method [7] achieves proper fluid orientation within the propellant tanks by continuously confining the propellant to the vicinity of the tank outlet. A positive expulsion device usually consists an outer tank shell and an inner moveable expulsion device. Frequently used expulsion devices are: (1) metallic diaphragms, (2) elastomer diaphragms, and (3) moveable pistons.

The metallic diaphragms are desirable because of their long term storage capability with the propellants. They will not be used on this project because the extremely low temperatures required for Liquid Hydrogen would cause the aluminum to be cold-worked and fail by fatigue after only one expulsion cycle.

An alternate method of obtaining positive expulsion in cylindrical tanks is a movable piston actuated by a pressurant gas. To prevent leaking during operation, seals will be required. The seals may be piston-type rings or some type of metallic wiper. In either case, the dimension and surface finish of the tank inside diameter should be maintained relatively accurate and smooth. The pressure differential across the moveable piston required to overcome friction during operation increases the required pressurant pressure and the tanks structural loads. Another disadvantage of this method is that the center of gravity shifts during use. Also this method adds mechanical complexity and a need for more accurate clearances.

The main propellant tanks on the LCTV will use an Elastomer Expulsion Diaphragm [7]. Elastomer-type diaphragms are applicable to most tank configurations and often offer a more efficient utilization of tank volume. This design takes advantage of the stretching properties of a pure elastomer and uses the diaphragm as a bladder. As the bladder is pressurized and inflates, the propellant is displaced and positively expelled. By positioning the bladder in the geometric center of the tank, the propellant is uniformly confined and the center-of-gravity remains stationary. This system is capable of repeated expulsion and refill cycles. An inherent disadvantage of pure elastomers in storage contact with many propellants is tensile strenght degradation as a function of time. The exact material will not be specified, but it will be prescribed as one that will be able to withstand the environment of the Hydrogen and Oxygen tanks. See Figure 3-001.

Tank Structure

In addition to considerations of propellant compatability and operational temperature ranges, selection of construction materials for propellant tanks is based on their strength-to-density ratio at a given temperature and on their ductility. For a given working pressure, the lightest tank structure will be the one made of the material with the highest ratio of ultimate strength to density. Following are some of the most frequently used materials and their properties at room temperature. [7]

Aluminum Alloys, such as 6061-T6, 6066-T6, and 2014-T6. Average density = .1 lb/cu. in., Fy up to 60,000 psi, Fu up to 70,000 psi.

Stainless Steels, such as AISI 347 (for low pressure tanks only), 17-7 PH and PH 15-7 Mo. Average density = .285 lb/cu. in., Fy up to 200,000 psi., Fu up to 220,000 psi.

Fiber glass, filament wound with an aluminum-alloy liner. Average density (fiber glass only) = .08 lb./cu. in., Fu = 120,000 psi.

The fiber glass tank design will not be used of the LCTV because it can not handle the low storage temperatures of the main propellants. Although the stainless steels have a slightly better ultimate strength to density ratio, an aluminum alloy will be used because of its ease of manufacture and repair.

Using the formulas in reference [7] to calculate the wall thickness required to withstand membrane stresses due to internal tank pressure and the total tank weight, the following specifications were found. (Note: These calculations do not include the expulsion equipment or the cryogenic equipment weight, only the bare tank.) All tanks are aluminum 6061-T6.

Hydrogen tanks:
- Maximum pressure = 100 psi (690 kPa)
- Wall thickness = .190 in. (4.82 mm)
- End thickness = .095 in. (2.41 mm)
- Total weight (each) = 4550 lb. (2060 kg.)

Oxygen tank:
- Maximum pressure = 100 psi (690 kPa)
- Wall thickness = .154 in. (3.92 mm)
- End thickness = .077 in. (1.96 mm)
- Total weight = 2820 lb. (1280 kg.)

Helium tanks:
- Maximum pressure = 2000 psi (13,800 kPa)
- Wall thickness = 1.2 in (30.5 mm)
- Total weight = 2200 lb (1000 kg.)

The data for the RCS tanks may be found in reference [15].

Attachment of Tanks

Due to the thin membrane structure of the large tanks, reinforcing rings will be placed around them. These rings will then be attached to the structure of the LCTV with mounts that will allow both the tanks and the structure to displace a small amount. The mounts will be designed so that there will be as little as possible heat conducted through them from the structure to the tank. The mounts will also be required to isolate the fuel tanks from the inherent vibrations of the structure. After these considerations, mounts such as the ones currently used on the Space Shuttle will be used, except that they will be redesigned so as not to permit heat transfer to the tanks. Also, a smaller scale of the mounts will be used since the LCTV accelerates at a much lower rate and the fuel tanks on the LCTV are smaller and lighter than those used on the Shuttle.

Insulation and Cooling of Tanks

In design of cryogenic propellant tanks, there are several potential problem areas which may affect proper functioning and reliability:

(1) Properties of the tank construction materials at the cryogenic propellant service temperature range
(2) Thermal stresses induced in the tank structure by temperature gradients
(3) The relief of tank pressure caused by boiloff of the cryogenic propellants
(4) Thermal insulation of the tank walls

One reason that an aluminum alloy was chosen for the tank material is that aluminum posesses good mechanical properties at cryogenic temperatures. The thermal stresses can be analyzed by determining the temperature profile at various regions of the tank and may be minimized by discrete design approaches. The capacity of the tank relief valves should be based on the maximum anticipated boiloff rate due to the maximum temperature achieved by the tanks.

Liquid Hydrogen imposes serious tank design problems. This is mainly due to its very low service temperature and its relatively large specific volume. Design problems are especially acute with the hydrogen tank insulation. The difficulty arising in hydrogen comes from its tremendous boiloff rate, which is approximately 70 times that of oxygen. In the design of the LCTV, the oxygen tank is covered on each side by a larger and longer hydrogen tank. The hydrogen tank is also exposed to solar radiation on about 2/3 of its surface area. Since the hydrogen is at a much lower temperature than the oxygen, it will protect the oxygen tanks from high temperatures. The hydrogen tanks must be designed to keep the hydrogen boiloff rate very low since the fuel is being delivered from other sources. To keep the hydrogen at an acceptable temperature, both a cryogenic cooling system and adequate insulation will be used.

Almost all of the heat influx to the hydrogen tanks will come from solar radiation. The insulation used in the solar shields must be light weight, reliable, and have a very low heat conductivity. Excellent results may be achieved with a laminated-type insulation. This will employ a structure of aluminum foil and fiber-glass, possibly in multiple layers. The aluminum foils act as reflectors, effectively rejecting radiative heat, while the evacuated space in between prevents conductive heat transfer. This type of insulation can be easily applied to curved surfaces such as the tank itself. An outer shield may be used if this insulation does no prove to be adequate. The outer shield will be of a thin sheet of aluminum covered with either magnesium oxide or silver.

The two helium and the two sets of RCS tanks will be placed under the tank deck. They will be in the open area above the engines and between the support structure. Since they will not be protected by the structure, they will have insulation covered by aluminum plates to keep the heat out as well as to protect them from any debris that may be kicked up by the engines.

The cryogenic cooling system will be required thoughout the entire flight to prevent the hydrogen from boiling off. This system will be designed so that it is as light as possible while still producing enough power to cool 34,000 pounds of hydrogen.

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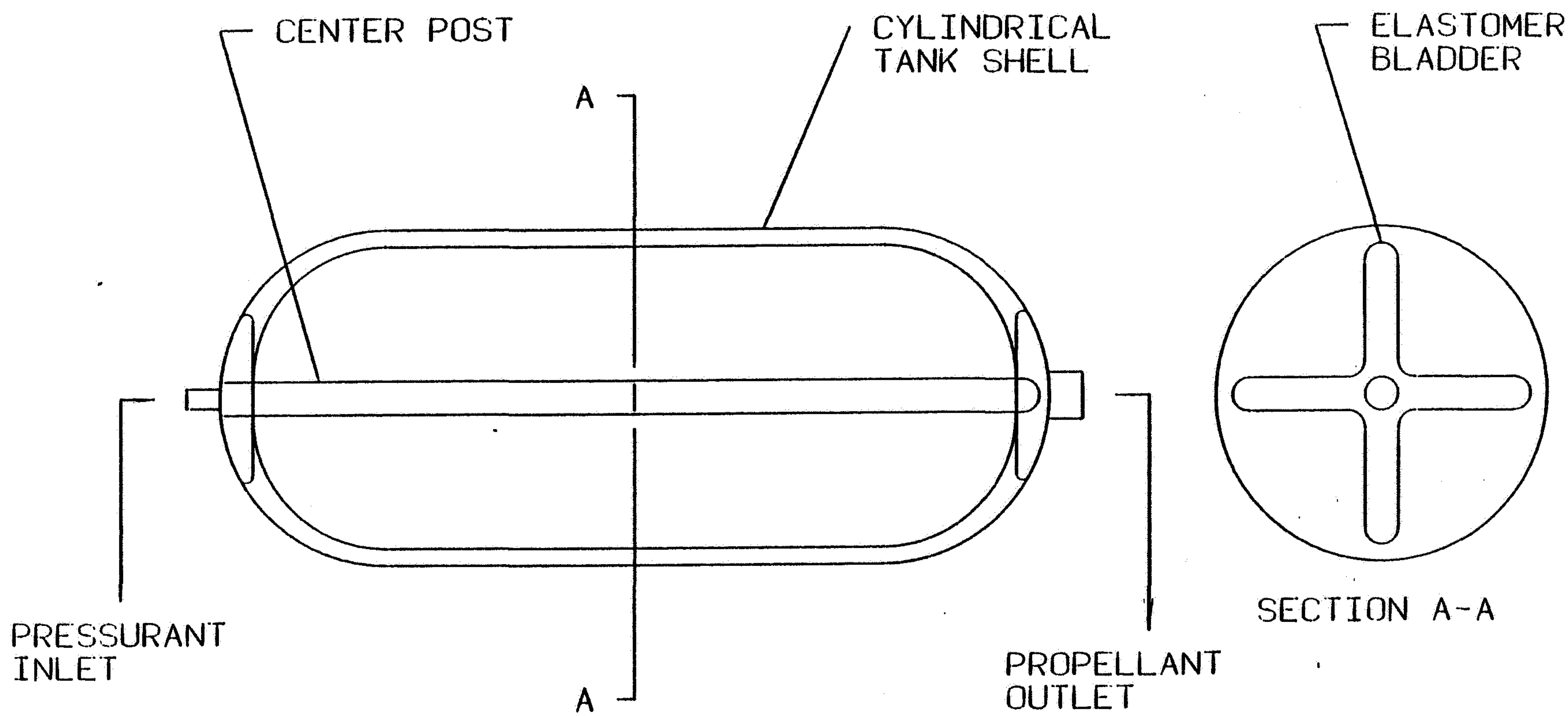

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PAYLOAD AND PAYLOAD EXCHANGE SYSTEM

The payload exchange system includes docking, payload exchange and refueling. After investigating other methods of payload exchange, it was decided that the Lunar Cargo Transport Vehicle (LCTV) will rendezvous with the Orbital Transport Vehicle (OTV) in lunar orbit. This method induced the need for a docking system. The development on the propulsion system has recommended that liquid hydrogen be used as fuel. Because this is not a readily available resource on the moon, the OTV will be required to bring a supply to the LCTV from earth. Thus the need for refueling during the payload exchange.

The payload could be transported from the earth's surface to earth's orbit by shuttle, from earth's orbit to lunar orbit by OTV and from lunar orbit to the lunar surface by LCTV; or from the lunar surface to the earth's surface via the same route; or making any stop along the way. The payload will be in modular form using several different size containers, but since the payload will be shuttled, it should be able to be treated as one entity. Thus the need for a pallet. The containers will be loaded onto the pallet, and it can then be treated as one item. If the payload does not fit into any container, it can be attached to the pallet by cable and winch.

Pallet

The pallet to be used is a modified version of one already used in the space shuttle program. This pallet has the capacity and size of the space shuttle payload. Since the worst enviroment this pallet will have to endure is during space shuttle launch, no stress analysis will be needed. One modification will be to latch the pallet to an arm that will switch the pallet from the LCTV to the OTV. This will be discussed later in the Payload Exchange section. Other modifications will allow the pallet to attach to the LCTV. A female pyramid (i.e. one that will match the one described in the Structures section), and three holes each on two support beams for the hydraulic cylinders, discussed earlier, which will lock the pallet down. The last modification will be to have the containers or payload attach to the pallet.

The mechanism used to attach the payload to the pallet is similar to some door latches on the B-1 Bomber. The container will have four shafts protruding from the bottom with cones on the end of each shaft (see fig. 4-001). The cones will go through holes in the pallet, and then into holes in a column inside the pallet (see fig. 4-002). The column will slide down and lock the containers in place. Since the pallet will be loaded in a shirt sleeve environment, the movement and locking of the column can be done manually. If a cable and winch is used, the cone will be on the end of the cable.

The containers will modularize the system. Four containers 12

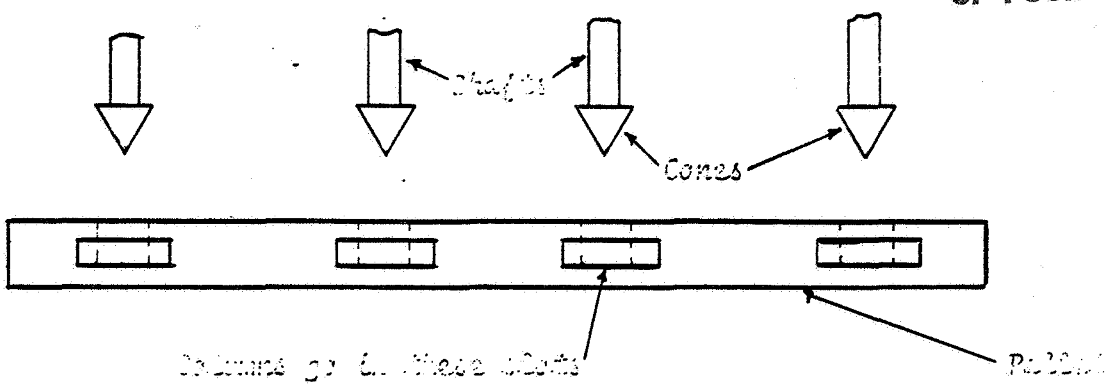

Figure [illegible]-001. Cones over holes in Pallet.

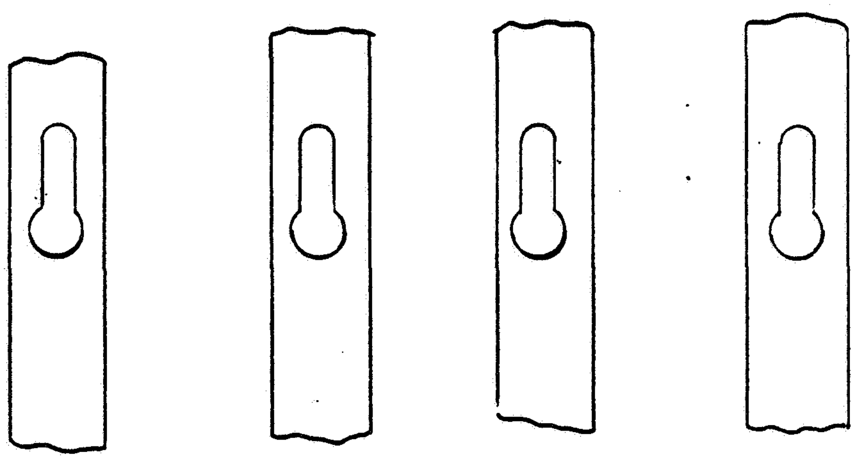

Figure [illegible]-002. Columns with holes and slots.

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ft. X 12 ft. X 12 ft. (3.7 m X 3.7 m X 3.7 m), or two containers 12 ft. X 12 ft. X 25 ft. (3.7 m X 3.7 m X 7.6 m), of one container 12 ft. X 12 ft. X 55 ft. (3.7 m X 3.7 m X 16.8 m), or any possible combination of these will be carried on the pallet. By using different size containers, different payloads can be transported on the same mission. The large container can be modified to transport personnel by adding a life support system.

Payload Exchange

During the design of the LCTV, there were several different ideas to actually exchange the payload. One idea was to have the LCTV leave the payload in orbit for the OTV to come by and pick it up. This was not desirable if personnel were possibly involved, and would be difficult for controls to handle. The deployment of a docking and refueling station in lunar orbit, which both the LCTV and OTV would dock to was reviewed. Since the LCTV was required to dock to this station, it was decided to have the LCTV dock to the OTV in a stable orbit. This would not require the OTV to perform any docking maneuvers.

Once it was decided the LCTV would dock to the OTV, the process of payload exchange was derived through an industrial engineering thought path. By moving both of the payloads off the LCTV and the OTV at the same time, and switching them at the same time, the optimum process will be reached.

The Payload Exchange Refueling Unit (PERU) will be at the long end of the LCTV. This unit will be the docking junction between the OTV and the LCTV, as well as perform refueling and payload exchange. Docking and refueling will be discussed later in this section. The PERU will have an arm that will move up to the level of the pallets, rotate 90 degrees to hook onto the pallets, lift the two payloads to clear the two vehicles, rotate the two pallets 180 degrees and lower the payloads. This process is illustrated in figure 4-003.

The lifting of the payload will be done by a hydrualic cylinder which will be inside the unit with the shaft that is inside the cylinder bolted to the arm. Since this shaft will not support a tourque, two rods that are bolted to the arm and go through a rotor will support the tourque needed to rotate the payloads. This rotor (see drawing 4-009), which will have the hydraulic cylinder inside, will be rotated by a motor through a gear train. To minimize the loads on the rods and the arm, the process of lifting and rotating will be done slowly at constant acceleration. Lifting and lowering the two pallets 5 ft. (1.5 m) will take 5 mins. each, and rotating the payload 180 degrees will take 5 mins. If the gear (on the rotor) to pinion (on the motor) ratio is 7.5, then the motor will have to produce 80 ft. lbs. (108.5 Nm) for the first 2.5 mins. and then decrease to zero over the next 2.5 mins. The motor and hydraulic system will be controlled by a microprocessor in the PERU, which will be initiated by the main microprocessor unit of the LCTV.

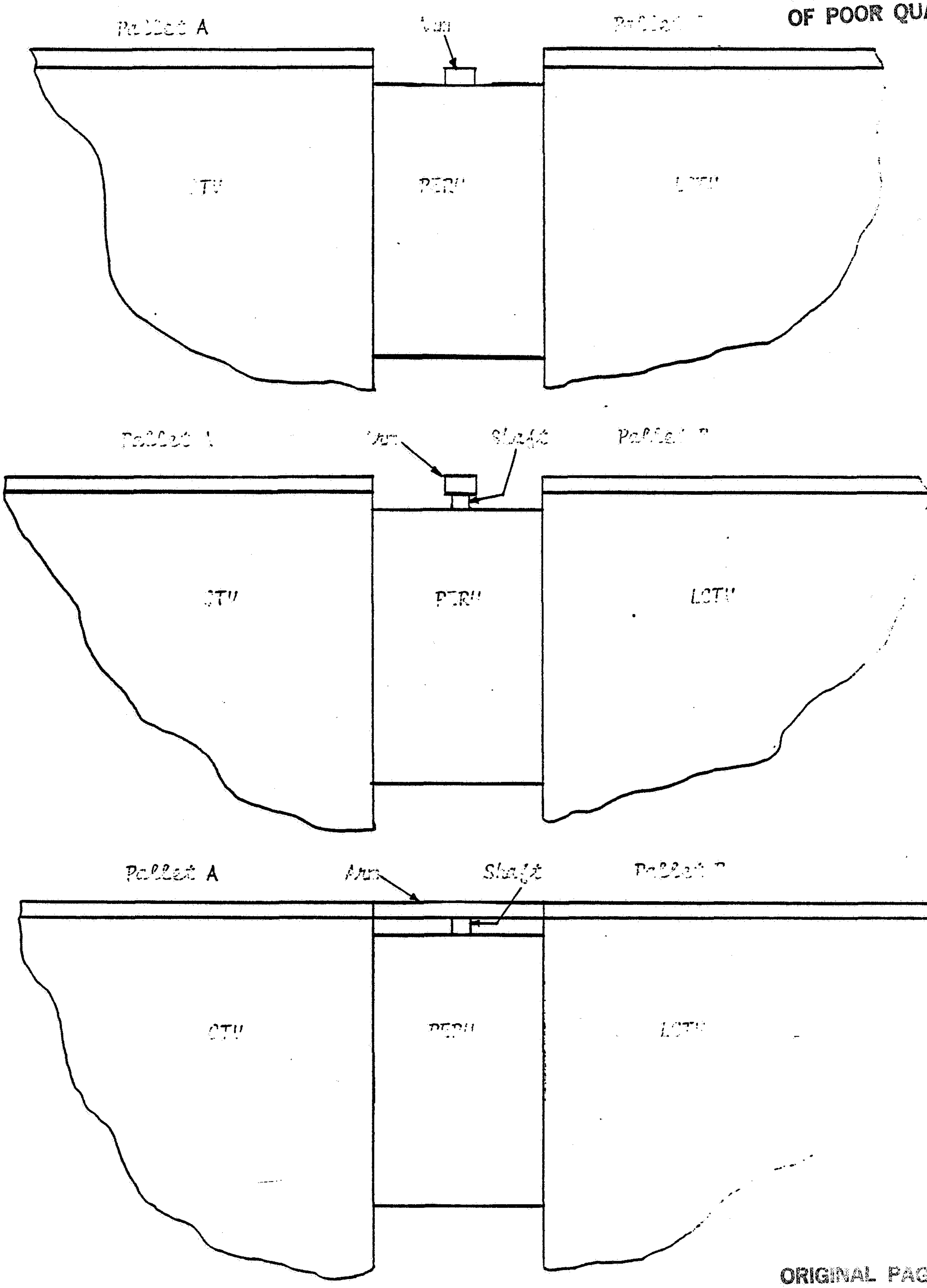
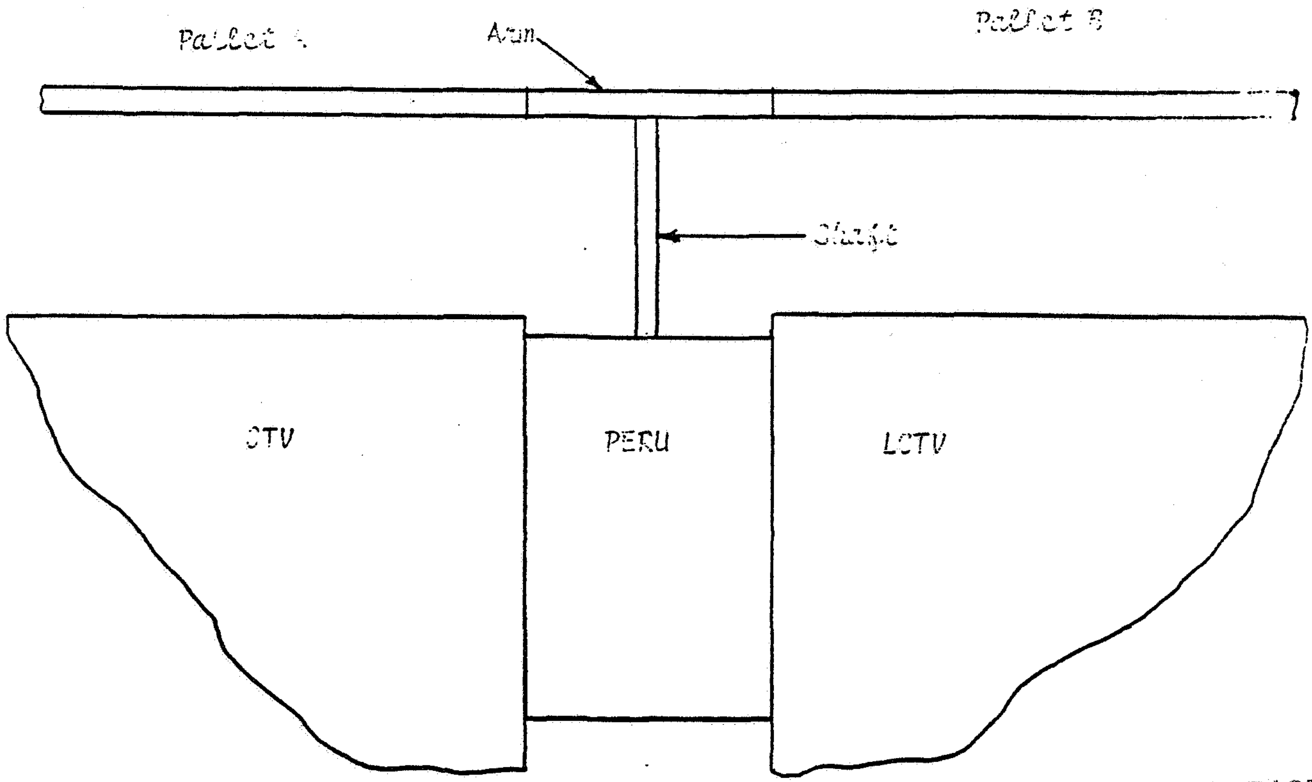


Figure 4-003. Payload exchange of Pallets A and B (some details omitted).



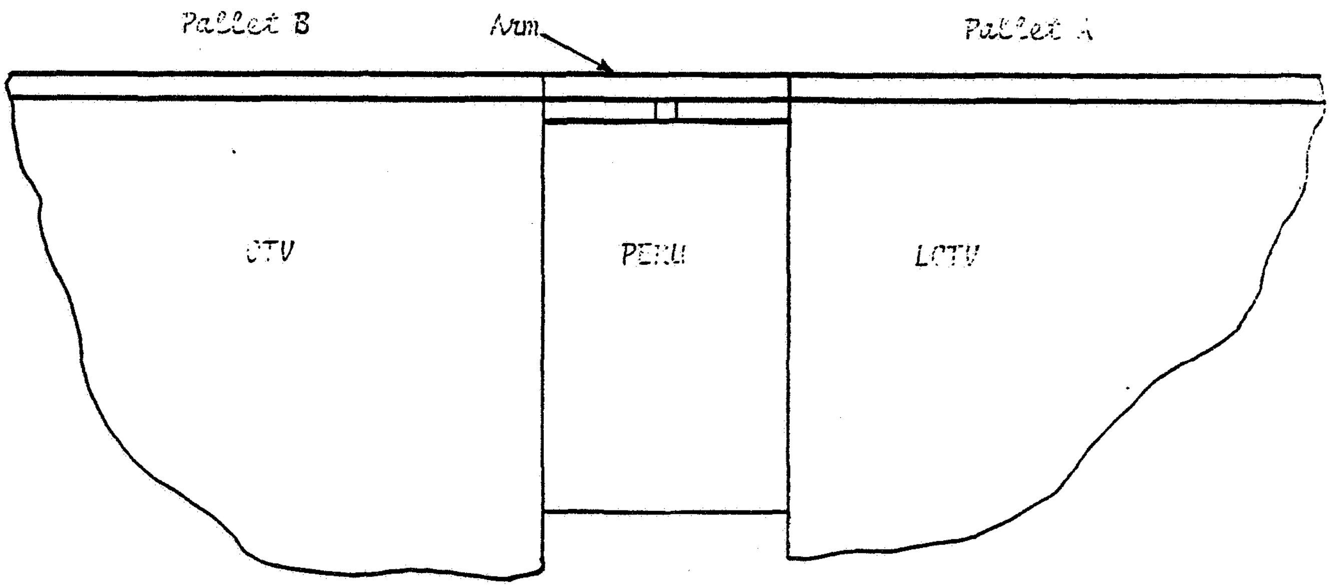


Figure 4-003 (con't). Payload exchange of Pallets A and B.
[Some details omitted]

One problem with this unit is the bearings for the rotor. Normal ball bearing with bore diameter of 2.5 ft. (.75 m) can be used to restrict radial displacement and provide minimal friction. Because of vibration and acceleration during lift-off and landing, the rotor must also be restricted in the lateral direction. To minimize friction and lateral displacement, a bearing must be developed to be placed on the end surfaces of the rotor (see fig. 4-004). The bearings for the bottom of the rotor will be in the body of the PERU, while the bearings for the top two surfaces will be in the retaining plate of the PERU (see drawing 4-008).

The latch used to hook the pallet to the arm was optimized to use the smallest amount of rotation, which would use the smallest part of a gear. One idea was to latch on by locking into the pallet and then "backing out" to unlock. This would need an extra 90 degrees of gear for a total of 270 degrees. By not having to "back out", only 180 degees of gear is needed. The latch developed here will use three small hydraulic cylinders for each end of the arm. The arm will rotate between two plates, one bolted to the top of the pallet, and one bolted to the bottom (see fig. 4-006). The top plate has two holes, and the bottom plate has one hole in the middle. The three hydraulic cylinders will extend and lock into the holes in the plates.

Docking

The docking will be done by the LCTV with the OTV in a stable orbit. The docking device will again be similar to the door latches on the B-1 Bomber. Two cones, one foot (.3 m) in diameter at the base, will be on the end of two shafts protruding from the end of the OTV. A guidance system, which will be discussed later in the Controls section, will line up these two cones with two inverted cones in the PERU on the LCTV (see fig. 4-005). The hole will be three feet (.9) in diameter at it's opening. This will give the guidance system some tolerance during alignment. The cone will be locked onto the PERU in a manner similar to that used to attach containers to the pallet. The difference being that the column will be moved by a motor controlled by the PERU microprocessor.

Refueling

The refueling system has not been thoroughly investigated, but the intent is to use a quick connect/quick disconnect fuel nozzle. These types of nozzles are used on Indy race cars and throughout the aerospace industry to prevent spillage. A similar system can be developed for use on the LCTV. The two, two foot (.6 m) diameter holes in the PERU are allotted for the use of refueling. If a quick connect is used, the nozzle will have to be connected after the LCTV is positively docked to the OTV.

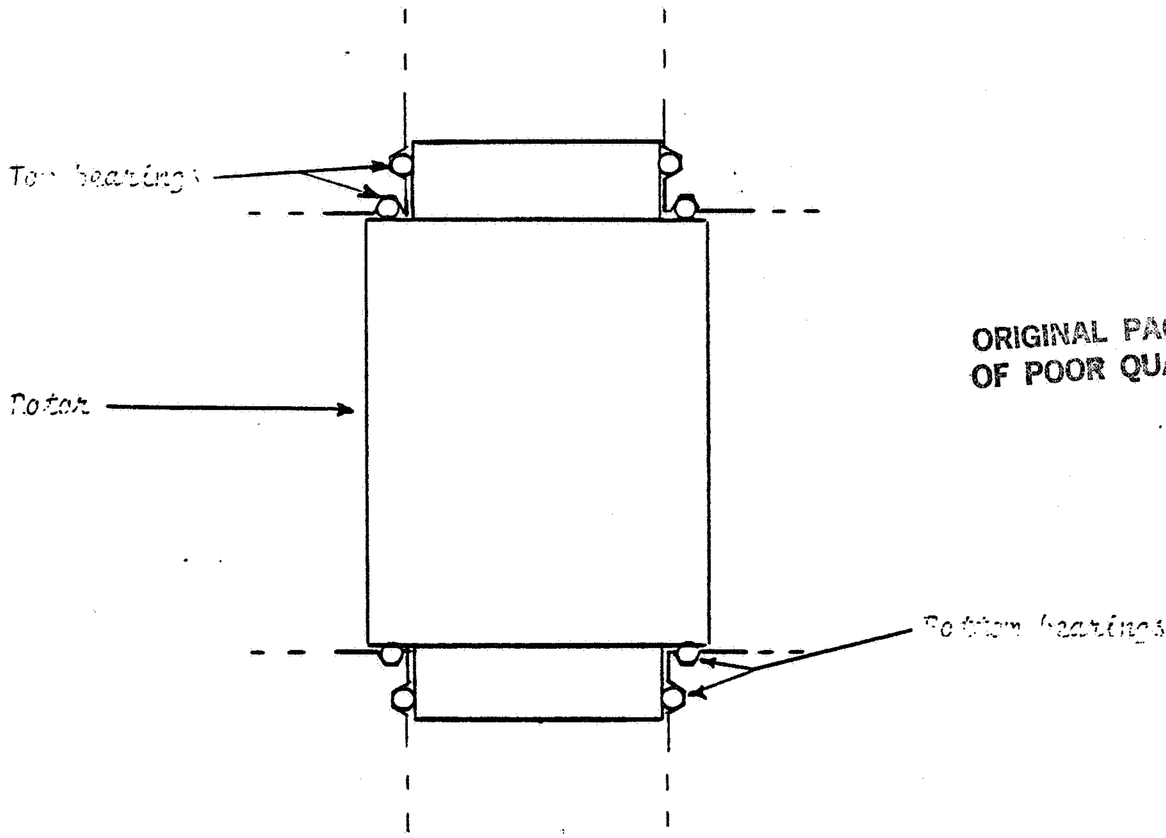


Figure 4-024. Bearings for PERU rotor.

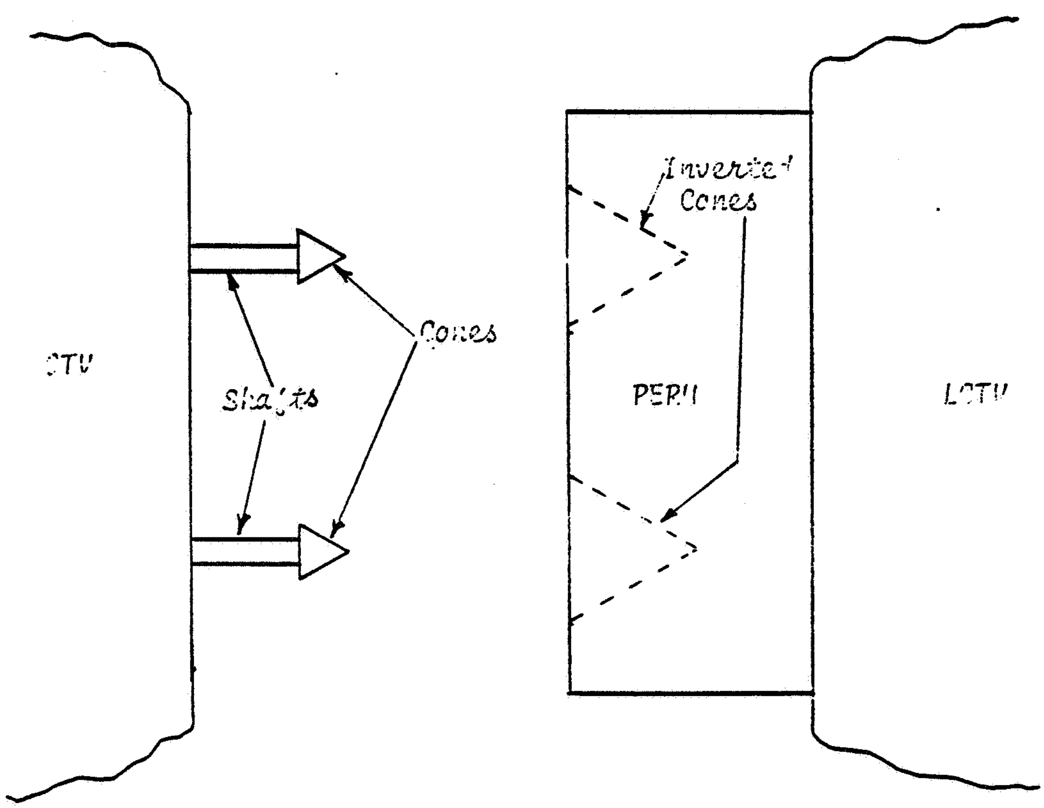


Figure 4-025. Alignment of cones during docking.

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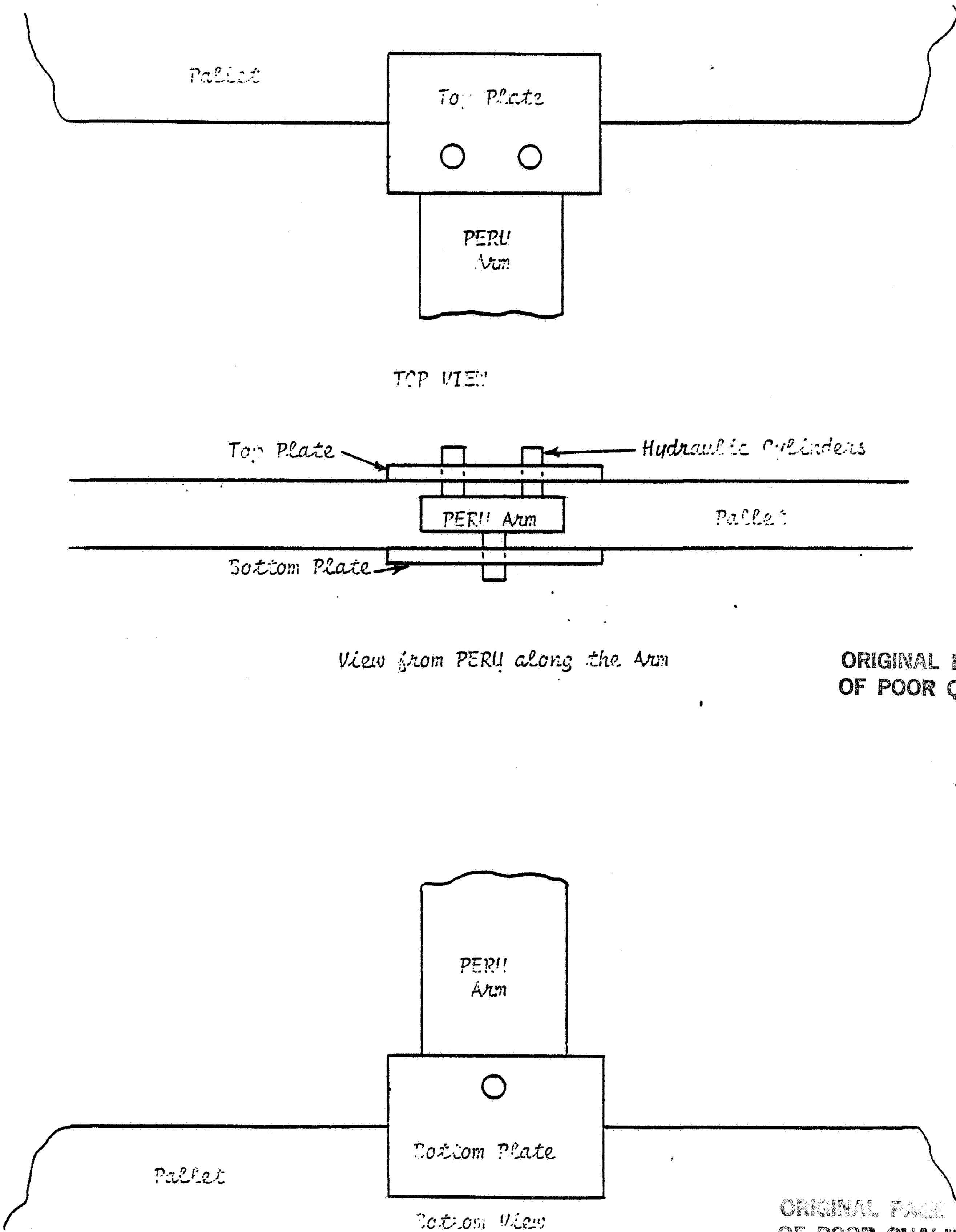
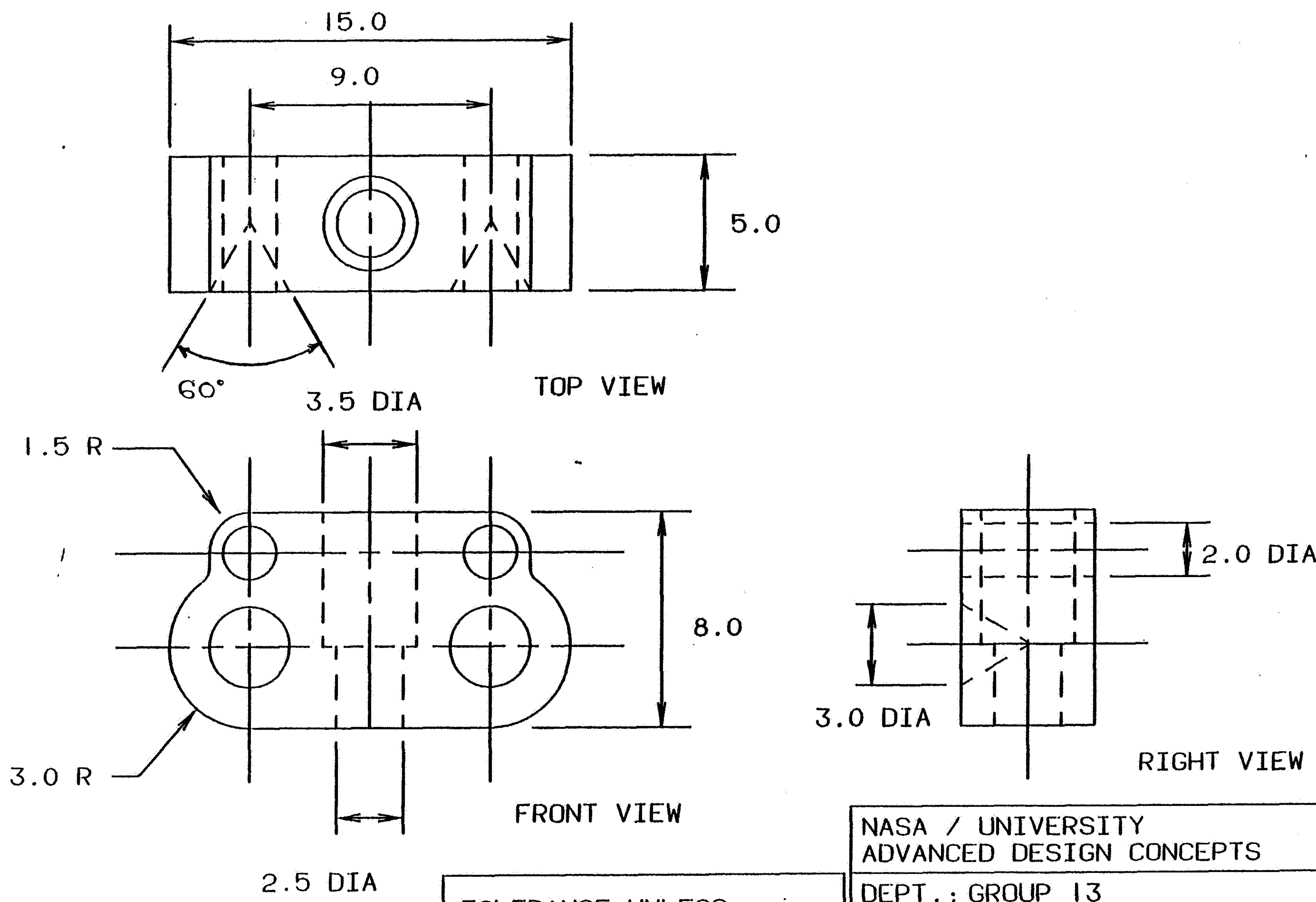


Figure 4-00[illegible]. PERU Arm/Pallet latching mechanism.



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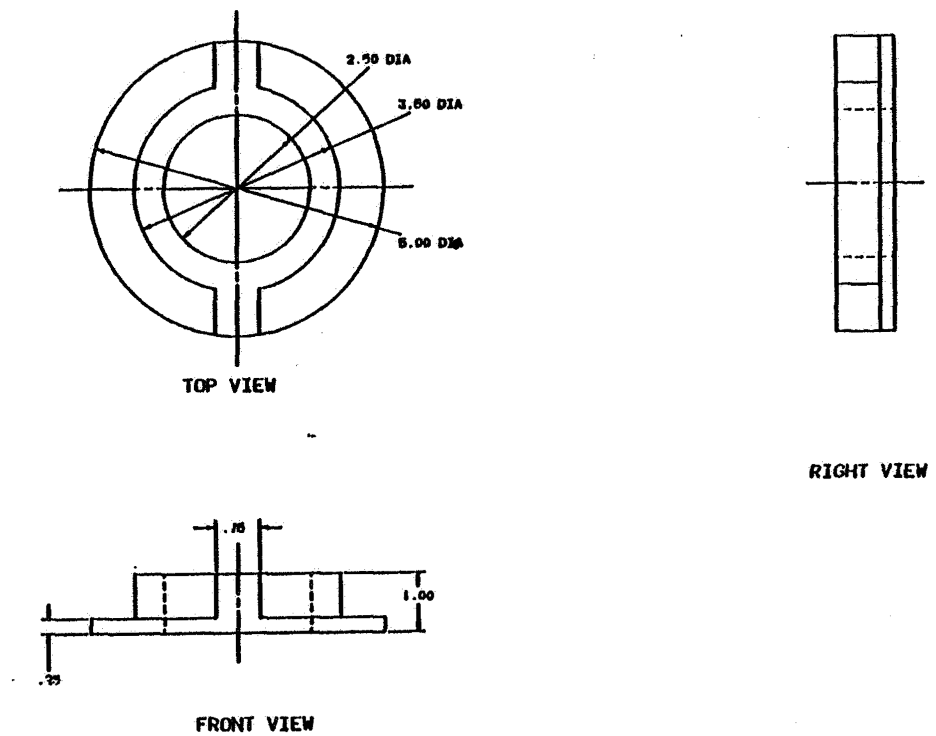

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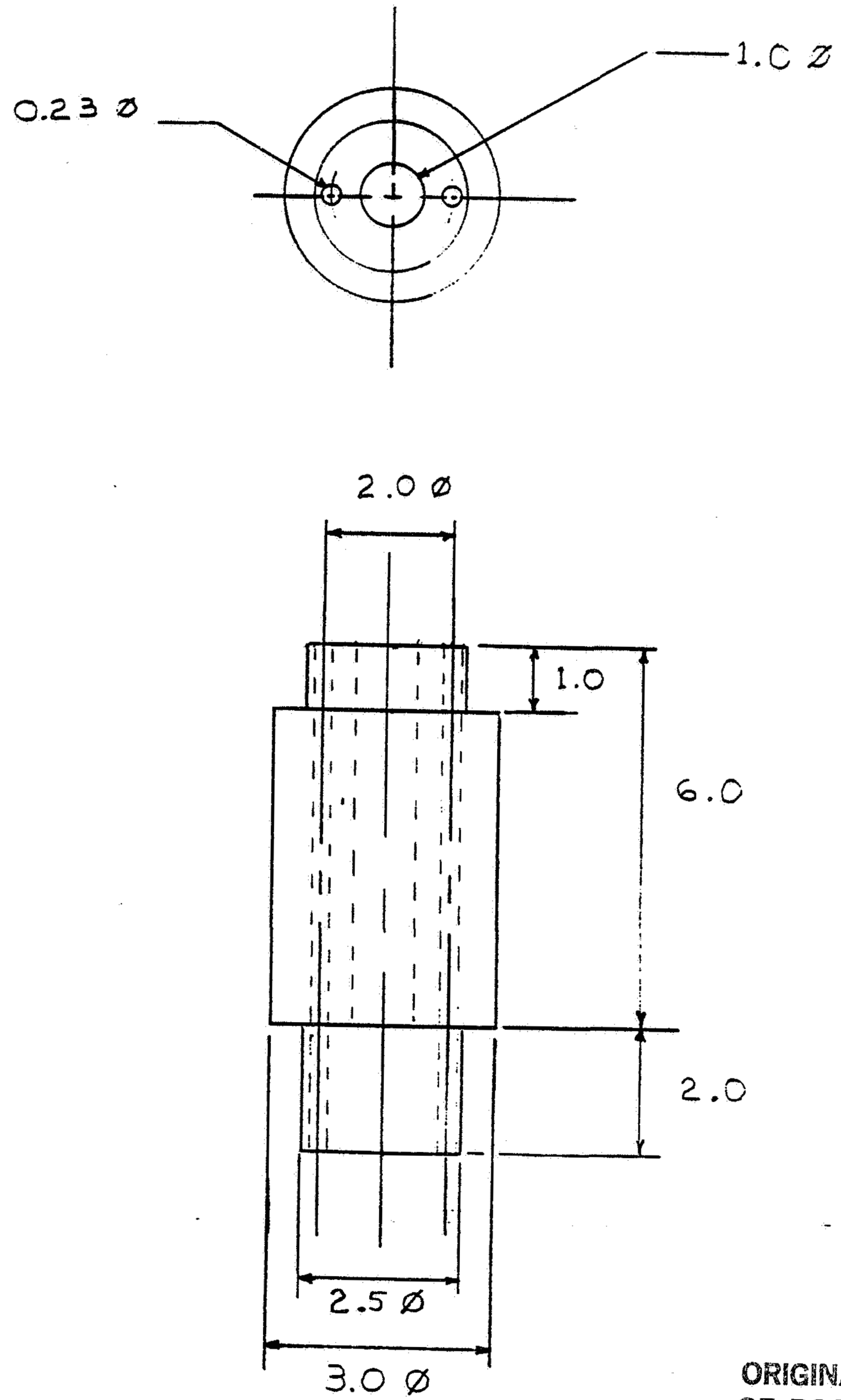

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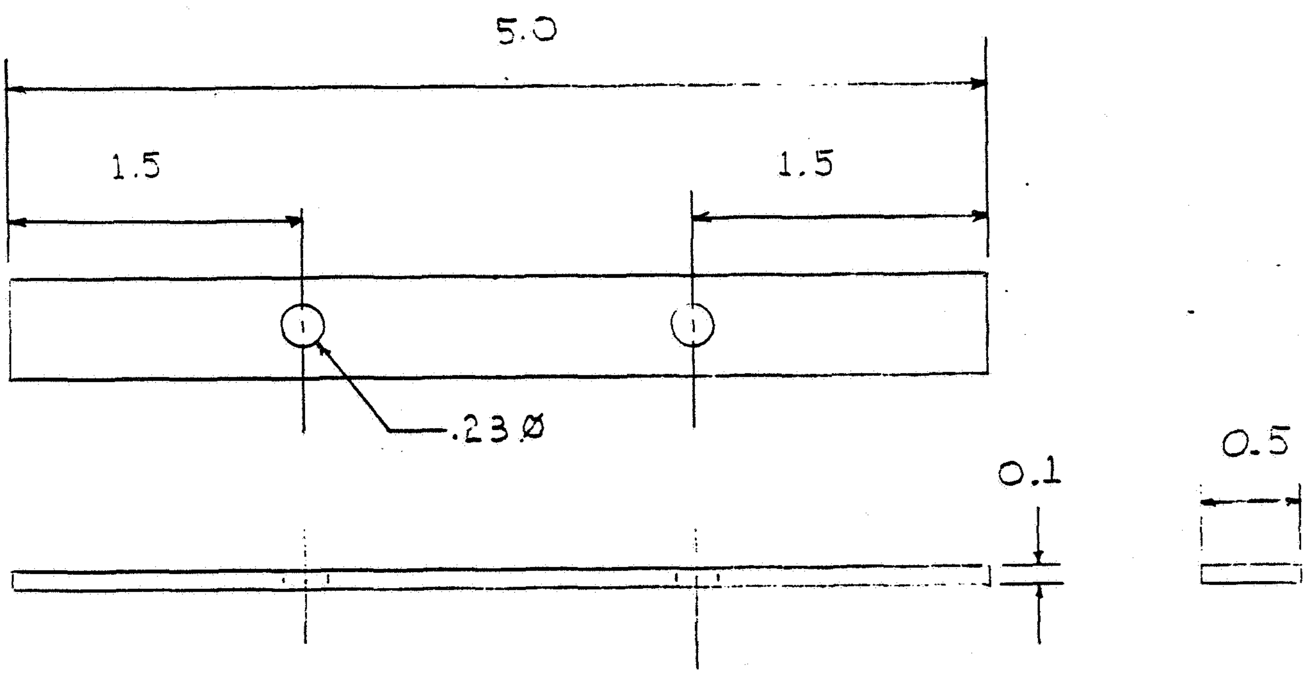

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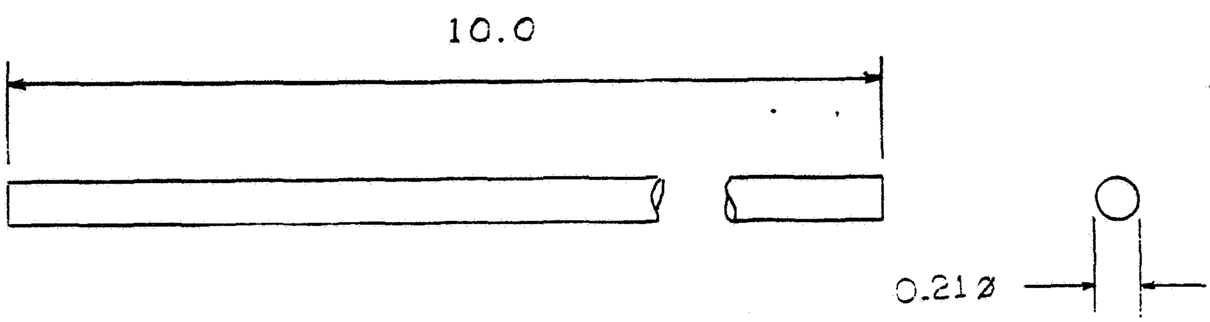

PERU ROD (4-011)

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LANDING GEAR

The landing gear for the LCTV has not been a major concern; many vendors supply standard landing gear for aerospace vehicles that can be slightly modified to suit the LCTV application. The landing gear will most likely use an assembly of shock struts and bracing members. Due to the harsh environment that the LCTV will encounter some modifacations will be required.

The vehicle will operate in a vacuum under zero-g conditions. The mechanism will be required to sustain temperature ranges of +/- 210 C. The mechanical performance characteristics of the shock strut should provide damping to minimize ground resonance and incorporate some metering devices for energy absorbtion.

A standard shock strut mechanism controls the flow of a gas-oil combination to provide the damping necessary. In order for the shock strut to perform well the gas should not disperse throughout the oil. Under zero-g conditions, however, this may happen unless a barrier is present between the gas and oil.

As the LCTV lands it is very possible that a lateral velocity will exist. This is a critical concern under emergency landing conditions. Therefore it is suggested that the member of the landing gear assembly which contacts the lunar surface is able to damp out lateral velocity. As an alternative to this, the structure of the landing gear could be designed to absorb the energy from the lateral motion and should be considered in design.

CONTROLS AND ELECTRONICS

Introduction

Thanks to the invention of modern micro-computers, automatic control of a lunar cargo transfer vehicle is possible. This section will outline how such a vehicle would operate. Since the state of the art in computer systems is changing almost daily, this description may become outdated as far as available equipment is concerned, but the general format of the system will remain the same.

Control System

The main control system will be made up of several sub-systems, including navigation/guidance, electrical power distribution, main propulsion and control rockets, and error testing. These subsystems will report their status and receive commands from the main mission controller(MMC), which will have the job of supervising the operation of the vehicle in all stages of flight. Each subsystem will have its own microcomputer which will handle the job of interfacing the main mission controller with the actual hardware of the vehicle. This allows the main mission controller to mantain a supervisory mode, only handling very high ordered mission functions, letting the subsystem computers handle the routine operations. In the event of a MMC breakdown, each individual subsystem will be able to execute a predefined set of commands in order to insure the safety of the LCTV.

Main Mission Controller

The main mission controller consists of all the hardware and software necessary to operate the LCTV under normal conditions. The hardware will consists of 3 computers, all identical, connected in a redundant group through a poller, a device which will receive commands from all three computers and issue the command that at least two of the computers agree on. Each computer will run the same mission program as part of the fail-safe system.

At the start of the mission, prior to lift off from the moon's surface, the computers will be loaded with the mission profile program. This program will contain all the data pertinent to the current mission, such as where the OTV is in orbit and where to land. The computers will use this data to issue commands to the main propulsion and control rockets and then use information from the guidance system as feedback.

If at any time a subsystem senses an error in itself, the subsystem will issue an interrupt to the MMC, which will then be handeled by a portion of software called tasks. Tasks will have priority over all other operation of the LCTV but also must only take a limited amount of time. On the lunar lander of the Apollo missions, a task could only take up to two minutes of the computer's time. Since tasks on the LCTV will only handle errors, they should be limited to less than 15 seconds of the computers time. If multiple errors occur at the same time, then the MMC must decide which error is more threatening to the success of the mission and execute it first. The MMC will then handle the second error if it is still present.

When the MMC is not executing tasks, it will execute jobs. Jobs are controlled by the executive program resident in the 3 computers. These jobs are either called for by the mission profile program or by various subsystems. Each job call will consist of an address and a priority, the address telling the computer where the subroutine for that job is in memory and the priority informing the MMC how important the job is. Every 3.08 milliseconds (1000 individual instructions) the MMC will check to see if any other jobs with higher priorities have been called for. If so, it will execute the higher priority job, putting the interupted job on hold. Any time a task is requested, all jobs will be put on hold.

The best choice for the three computers in the MMC would be a modified IBM AP-101 microprogram controlled computer, which is also used on the Space Shuttle. This computer has 104,496 words of memory and a word length of 36 bits. It uses floating-point calculations at a rate of 325,000 calculations per second. Since this computer has been proven in the field and fits the specifications for a control computer, it would be the logical choice for use aboard the LCTV.

Navigation and Guidance

Navigation and guidance will utilize intertial guidance along with a Navigaion/Guidance Computer(NGC). The main purpose of the NGC is as feedback loop for the MMC and propulsion unit. The mission profile program that is loaded into the MMC will also be loaded into the NGC. The NGC will then monitor its own various sensors and compare their values to those of the mission profile program. If these values differ, the NGC will decide if to request a job or a task from the MMC. Almost all errors in navigation will be handeled by a job unless it is ascertained that the error is threatening the mission.

The navigation and guidance system will use three precision instruments for its job. These are:

1. gyroscopic devices
2. linear accelerometers
3. precision clock

The first two of these devices will be vehicle-frame mounted sensors as opposed to gimbal mounted due to the reduction in weight and size. The drawback with vehicle frame mounted systems is that their values need to be processed before the values can be used. This problem will be alleviated by attaching a single-chip microcomputer, such as a 6801, to each sensor to pre-process values for the NGC.

Inertial guidance was selected over other guidance systems, such as optical tracking or satellite tracking, because of the short mission time of less than two hours (see Flight Dynamics) and because of the high reliability of inertial guidance systems. Prior to leaving on a mission, the system can be re-calibrated.

Once in range of the OTV, a homing guidance system will take over. The prelimainary rendezvous will use a standard doppler shift radar system to manuever the vehicles within 50 feet (15.24 meters). Once within range, an optical system using lasers will take over. This system will use six lasers mounted on the OTV, one on each side, which will scan through 180 degrees. The OTV will turn each laser on in sequence and transmit a radio signal so that the LCTV will know which laser is on at what time. By measuring the light falling on sensors mounted aound the LCTV, the NGC will be able to inform the MMC of the LCTV's position in respect to the OTV. The MMC will then use the control rockets to align and dock the LCTV with the OTV.

During rendezvous and docking, the Navigation and control system will be sending position reports to the MMC computer almost continuously. Since any major problem will take time to arise (and could be handeled on a task basis), position reports will have a priority lower than the priority of jobs to the control rockets.

Upon completion of the payload transfer in orbit, the LCTV will undock with the OTV and use inertial guidance to return to its base. Since some drift is to be expected with the guidance system, the LCTV will also home in on a transmitter located at its landing point. As the LCTV approaches touchdown, it will use a microwave scanning beam landing system(MSBLS). This system is used on the Space Shuttle and will give the NGC information regarding elevation, azimuth angles, and range from the landing location.

As a backup to the inertial guidance system, a passive homing system will be onboard. This system will be able to use a series of satellites and/or ground stations to determine the LCTV's position. This system will only be used if the main system has a failure.

Communications-Internal

The most important part of the controls system is the ability for each subsystem to communicate with the MMC. All communications between the MMC and other subsystems will be through a single wire multiplexer/demultiplexer (SWMUX). The SWMUX will take the information that needs to be transmitted and convert it from parallel to serial form. This information is then sent across the single wire to a demultiplexer where it is converted back into parallel form to be used by a computer.

In deciding what type of single wire to use, the speed at which the computer can output commands must be considered. The computer used in the MMC has an instruction speed of 3.08 microseconds. Since a word is 36 bits, the wire should be able to handle a rate of 3.08usecs/36bits or 0.086 usecs/bit. This in turn gives a bit rate of 11.688 MHz. Since a coaxial cable can handle up to 500 MHz, this would be the logical choice. If at any time in the future a computer is used that would exceed the 500 MHz bandwidth limit, then the wire could be replaced with an optical fiber, which has an almost unlimited bandwidth. From a maintanance standpoint, the coaxial cable would be more suitble to stand up to the enviroment of space.

There are three main reasons for using the SWMUX. These are:

1. Area savings
2. Weight savings
3. Allows for redundancy.

Because only one wire is being run to each subsystem as opposed to 36 wires, several wires carrying the same information can be run through different parts of the vehicle to handle any failures in a single wire.

Communications-External

The external communcation system, not including navigation guides, will inform the ground facilities of the mission progress and receive commands from the ground if any error is detected in the mission. All communications will be telemetry data sent via the communications controller subsystem(CCS). The CCS will monitor all internal communications via the subsystems and the MMC and transmit back the pertinent information. If at any time the ground crew wishes to take over command of the flight, the CCS will inform the MMC to suspend operation and the CCS will then issue the commands it receives ffrom the ground to the various subsystems via the SWMUX.

Due to the bandwidth of internal communications (11MHZ), all external communications must be somewhat slower. Communciations in the KU-Band, with a frequency of 15.0034 GHz, is used by the space shuttle. This radio link has a bandwidth of about 1MHz. This means that if the ground crew were to take over control commands could only be issued at 1/11 the rate of te MMC. Since the ground will only take over control in times of emergency, this should cause no problem.

Main Propulsion Controller

The Main Propulsion Controller (MPC) will receive commands from the MMC and operate all the engines aboard the vehicle. The commands received from the MMC will include :

1. Engine Start-up
2. Engine shut-down
3. Change thrust
4. Gimabal engine
5. Fire control rocket

Each command will also have an address associated with it to specify which rocket or engine group the command is meant for. The MPC will then control the appropriate hardware to execute the command.

The MPC will control two valves for each main engine group (see Propulsion), the fuel tank valve and the oxidizer valve. Each main engine group will have two hydraulic actuators, operated in tandem, one for each engine. A position feedback system will be used to adjust each engine to the angle specified by the MMC. Also controlled by the MPC will be engine igniter in each engine used for engine start-up. The MPC will also monitor sensors placed throughout the engine system to insure proper operation and to detect any mission threatening errors.

When the MMC issues the engine start-up command, the MPC will open the fuel and oxidizer valves. Once the MPC senses that fuel is flowing into the combustion chamber, it will fire the engine igniter. If the MPC senses a dramatic change of pressure in the combustion chamber signifying engine ignition, it will stop firing the engine igniter and wait for the next command from the computer. Since the MPC opens the valves full for engine start-up, the engines will operate at 100% thrust until told otherwise by the MMC.

Control rocket firing will be either on or off so that the MPC will only have to tell each rocket to fire or to stop firing. The control rocket system will only have feedback via the Navigation and Guidance system. If a command is issued to move the ship and the Guidance system discovers the ship is not moving, it will inform the MMC to take corrective action.

As part of the fail-safe system, temperature sensors will be located along all fuel lines and various other locations on the ship. If at any time the temperature at a sensor raises above its specified value, the MPC will shut off all fuel flow in that area. Also the MPC will monitor pressure sensors in the combustion chambers of the main engines to assure the engines are operating. If an engine should fail to operate, the MPC will try to re-start it. If this fails, the MPC will shut off the other engine in that main engine group and inform the MMC that an error has occured and to start a pre-defined abort sequence (see Error Recovery).

Payload Handling Controller

The Payload Handling Controller will handle the hardware for the transfer of payload and fuel with the OTV (see Payload). This system will receive only one command from the MMC, that is to begin payload/fuel transfer. After payload and fuel have been transfered, this system will report back to the MMC that is has successfully completed its job.

Error Recovery

As with all systems, there is always a chance that an error can occur. To avoid any mission threatening errors, several features are built into the LCTV. The most important error recovery system is the redundancies in every system. Each system will be able to run a self test and switch to a back up system if any problem is encountered. Also onboard will be a Central Integrated Test System(CITS). The CITS will monitor various sensors around the ship to insure the LCTV is operating properly. If the CITS senses that any system is not performing its job, then the CITS will inform the MMC of the problem. As a last resort, the CITS can inform the Communications system that a major problem has occured. The CCS will inform the ground of the problem and the ground must decide if to destroy the LCTV. This will only happen if the LCTV is a threat to life or property.

Flight Dynamics

Due to the simplicity of the flight, the guidance system does not have to be very fast. After take-off, the LCTV achieves orbit in 8 minutes with an orbital velocity of 5440 ft/sec (1658m/sec). The LCTV stays in this orbit for 109 minutes until it starts its descent back to its starting point.

In this 109 minutes, the LCTV must dock with the OTV, exchange payloads and fuel, and undock. Since payload transfer will only take 15 minutes, this leaves 94 minutes to dock the two vehicles. Using the specified control rockets, this time restriction should be no problem. If the LCTV experiences any problems with time, then both the OTV and LCTV could remain docked for another orbit.

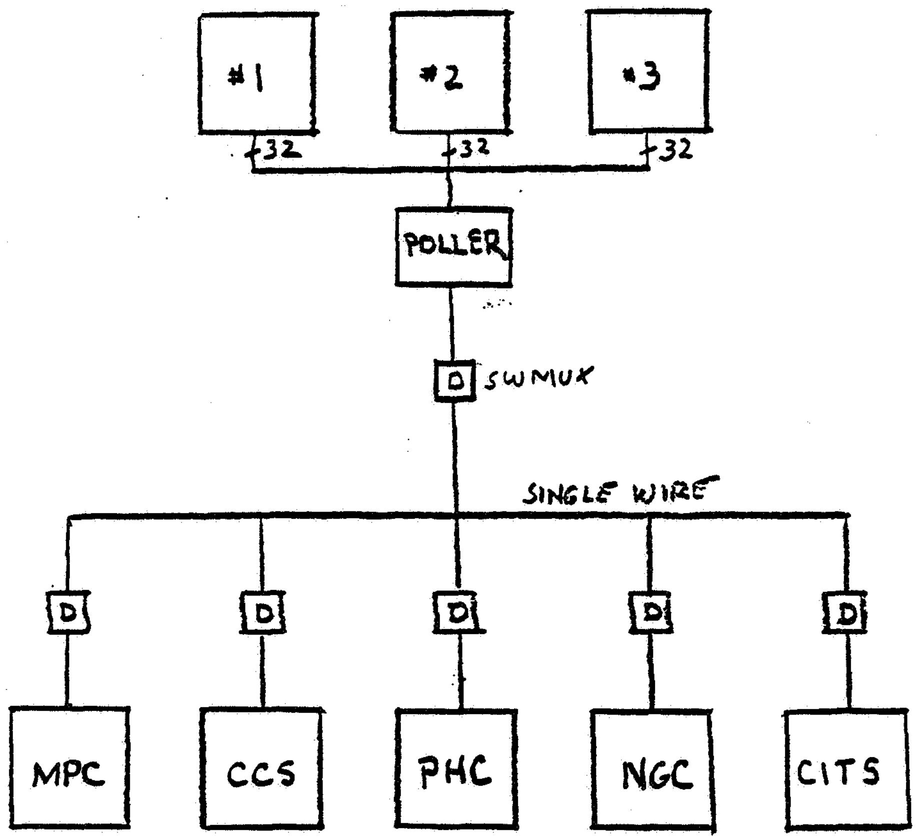

FIG 6-001 CONTROL SCHEMATIC

ACRONYMS

CAD	Computer Aided Design
CCS	Communications Controller System
CITS	Central Integrated Test System
LCTV	Lunar Cargo Transport Vehicle
MMC	Main Mission Controller
MPC	Main Propulsion Computers
MPS	Main Propulsion System
NGC	Navigation/Guidance Computer
OTV	Orbital Transfer Vehicle
PERU	Payload Exchange Refueling Unit
PHC	Payload Handling Controller
RCS	Reaction Control System
STS	Shuttle Transport System
SWMUX	Single Wire Multiplexer/demultiplexer

COMPUTER USAGE

LCTV Flight Simulation

To simplify engine selection, fuel system specifications, and flight control design, a computer simulation of the LCTV was written. Using the Microsoft Corp. version of the BASIC language on a microcomputer, the program was used to mathematically recreate the flight of a spacecraft in the lunar environment. The only external force applied to the LCTV is the lunar gravitational force. The program recalculates this force at every iteration since the force does vary with altitude. The thrust force applied against gravity is free to be varied by the simulation user. Using equations based on Newton's Laws, the program calculates the acceleration, the velocity, and the displacement of the spacecraft in two planes. Also, using theoretical fuel and oxidizer consumption values, the change in vehicle mass can be determined. The user can change, at any time, the attitude of the model and thus, the thrust vectors. There is an assumption here that the attitude change is essentially instantaneous between two iterations. Using the ability to change thrust levels and attitude, the spacecraft simulation can be "flown" in an approximation of the real flight.

Several different flight simulations were run to demonstrate the theoretical flight abilities of this design. The standard flight profile shows that the transporter can be flown to the expected altitude and orbital velocity and then returned to the lunar surface. Control design required knowledge of spacecraft flight characteristics in the event of failure of one of the engine loops. The simulater provided data that indicates that from approximately 2.5 miles (4.03 km.), the LCTV can abort the mission to the required orbit. Below this altitude, it is felt that the mission should be aborted to the surface. It was felt that the LCTV could be used as a surface to surface transport vehicle, but the simulation demonstrated that the maximum range that leaves enough fuel for a return flight would be 75 mile (120.75 km.) or less. Compared against flight costs, this appears to indicate that the LCTV is not suited for this type mission.

Computer Aided Design (CAD)

Many of the drawings in this report were done taking advantage of a computer drafting system. The system used was the IBM CADAM system. This system allowed easy drawing alteration in the event of design changes. It also allowed the designer to experiment with various different versions of the design.

```
1 CLS
2 REM  ********************************
3 REM  *     LCTV FLIGHT SIMULATION    *
4 REM  *          NASA/UNIVERSITY      *
5 REM  *     (TJL) 02/01/86  GA. TECH  *
6 REM  ********************************
7 REM  *      VARIABLE DICTIONARY      *
8 REM  ********************************
9 REM  *      MT:TOTAL MASS            *
10 REM *      AY:VERTICAL ACCEL.       *
11 REM *      AX:HORIZ. ACCEL.         *
12 REM *      VY:VERTICAL VELOCITY     *
13 REM *      VX:HORIZ. VELOCITY       *
14 REM *       T:TIME INCREMENT        *
15 REM *       X:HORIZ. POSITION       *
16 REM *       Y:VERTICAL POSITION     *
17 REM *       P:PERCENT THRUST        *
18 REM ********************************
19 REM *         INITIAL DATA          *
20 REM ********************************
21 Y=0*5280:X=0:T=1:VX=0:VY=0:LL=0
22 CF=.0174533: REM DEGREE TO RAD
23 MS=2020:      REM SPACECRAFT MASS (SLUGS)
24 MP=2020:       REM PAYLOAD MASS (SLUGS)
25 MF=6335:      REM FUEL MASS  (SLUGS)
26 GC=3.7302E-08:REM GRAVITY CONSTANT
27 MM=4.8429E+21:REM MOON MASS (SLUGS)
28 RM=5.7072E+06:REM MOON RADIUS (LBS.)
29 F=140000!:     REM MAX THRUST (LBS.)
30 FC=8.4467:       REM FUEL CONSUMP. (SL/S)
31 GOTO 67
32 REM ******************************
33 REM *     ITERATIVE SECTION      *
34 REM ******************************
35 K=K+1
36 QQ$=INKEY$
37 IF QQ$="T" GOTO 79
38 G=GC*MM/(RM+Y)^2: REM GRAVITY
39 MT=MS+MP+MF: REM TOTAL MASS
40 AY=((F*COS(LL*CF)*P/100)/MT)-G: REM VERTICAL ACCEL.
41 AX=((F*SIN(LL*CF)*P/100)/MT): REM ORBITAL ACCELERATION
42 IF YQ=0ANDAY<0THENAY=0: REM INITIAL Y=0 POSITION
43 Y=Y+VY*T+.5*AY*T^2: REM Y POSITION
44 IF Y<=0THENY=0 ELSE YQ=1
45 X=X+VX*T+.5*AX*T^2
46 VY=VY+AY*T: REM VERT. VELOCITY
47 VX=VX+AX*T: REM ORBITAL VELOCITY
48 MF=MF-(FC*(P/100))*T: REM CHANGE IN FUEL MASS
49 IF MF<=0THEN PRINT"OUT OF FUEL!":BEEP:END
50 IF YQ=0ANDY=0GOTO52
51 IF Y<=0 THEN PRINT"IMPACT WITH MOON!":BEEP:END
52 TM=TM+T
53 LOCATE 0,0
54 REM ******************************
```

SIMULATOR LISTING

```
55 REM *      SCREEN DATA OUTPUT       *
56 REM ******************************
57 PRINT" MASS   YPOS VELY VELX    GRAVITY  TIME"
58 LOCATE 0,2:PRINTUSING"#####";MF
59 LOCATE6,2:PRINTUSING"###.##";Y/5280
60 LOCATE12,2:PRINTUSING"#####";VY
61 LOCATE18,2:PRINTUSING"####";VX
62 LOCATE26,2:PRINTUSING"#.###";G
63 LOCATE35,2:PRINTUSING"###";TM
64 IF K=L GOTO85
65 GOTO 33
66 REM ******************************
67 REM *      INTIAL USER INPUT      *
68 REM ******************************
69 CLS
70 INPUT"INITIAL THRUST (%)";P
71 INPUT"PRINTER OPTION (Y/N)";ZZ$
72 IFZZ$<>"Y"THENL=1000:GOTO76
73 LPRINT" FMASS     YPOS     XPOS    VELY     VELX     GRAVITY    TIME
THRUST    ATTITUDE"
74 LPRINT"(slugs) (miles) (miles) (ft/s)  (ft/s)  (ft/s)    (sec)
(%)        (deg)":LPRINT
75 INPUT"TIME BETWEEN DATA PTS. (SEC)";L
76 CLS
77 GOTO 33
78 REM ******************************
79 REM *     SYSTEM ADJUSTMENT       *
80 REM ******************************
81 INPUT"NEW THRUST (%)";P
82 INPUT"ATTITUDE";LL
83 GOTO 38
84 REM ******************************
85 REM *       PRINTER OUTPUT        *
86 REM ******************************
87 K=0
88 IF ZZ$<>"Y" GOTO 33
89 LPRINT USING"#####.#";MF;
90 LPRINT USING"  ###.#";Y/5280;
91 LPRINT USING"   ###.#";X/5280;
92 LPRINT USING"#####.#";VY;
93 LPRINT USING" #####.#";VX;
94 LPRINT USING"     #.#";G;
95 LPRINT USING"     ###";TM;
96 LPRINT USING"     ###";P;
97 LPRINT USING"        ###";LL
98 GOTO33
99 END
```

SIMULATOR LISTING

FMASS (slugs)	YPOS (miles)	XPOS (miles)	VELY (ft/s)	VELX (ft/s)	GRAVITY (ft/s)	TIME (sec)	THRUST (%)	ATTITUDE (deg)
6215.5	0.1	0.0	80.4	0.0	5.5	10	100	0
6131.1	0.3	0.1	121.9	96.9	5.5	20	100	45
6046.6	0.5	0.4	164.2	194.6	5.5	30	100	45
5962.1	0.9	0.8	207.3	293.1	5.5	40	100	45
5877.7	1.3	1.5	249.4	394.0	5.5	50	100	55
5793.2	1.8	2.3	275.4	510.1	5.5	60	100	55
5708.7	2.4	3.4	296.8	630.5	5.5	70	100	60
5624.3	2.9	4.7	308.1	758.3	5.5	80	100	65
5539.8	3.5	6.3	314.5	890.1	5.5	90	100	65
5455.3	4.1	8.1	321.4	1023.1	5.5	100	100	65
5370.9	4.7	10.2	318.2	1161.7	5.5	110	100	70
5286.4	5.3	12.5	314.3	1302.1	5.5	120	100	70
5201.9	5.9	15.1	311.0	1443.7	5.5	130	100	70
5117.5	6.5	18.0	308.2	1586.7	5.5	140	100	70
5033.0	7.1	21.1	305.9	1730.9	5.5	150	100	70
4948.5	7.7	24.5	304.2	1876.5	5.5	160	100	70
4864.0	8.2	28.2	303.1	2023.5	5.5	170	100	70
4779.6	8.8	32.2	302.5	2171.9	5.5	180	100	70
4695.1	9.4	36.4	302.5	2321.7	5.5	190	100	70
4610.6	10.0	41.0	303.0	2473.0	5.4	200	100	70
4526.2	10.5	45.8	304.2	2625.7	5.4	210	100	70
4441.7	11.1	50.9	306.0	2780.0	5.4	220	100	70
4357.2	11.7	56.3	308.4	2935.8	5.4	230	100	70
4272.8	12.3	62.1	311.4	3093.2	5.4	240	100	70
4188.3	12.9	68.1	315.1	3252.2	5.4	250	100	70
4103.8	13.5	74.4	310.8	3415.5	5.4	260	100	75
4019.4	14.1	81.0	301.5	3582.3	5.4	270	100	75
3934.9	14.6	87.9	292.6	3750.9	5:4	280	100	75
3850.4	15.2	95.2	284.3	3921.3	5.4	290	100	75
3766.0	15.7	102:8	276.5	4093.5	5.4	300	100	75
3681.5	16.2	110.7	269.3	4267.6	5.4	310	100	75
3597.0	16.7	119.0	262.7	4443.6	5.4	320	100	75
3512.6	17.2	127.6	256.6	4621.5	5.4	330	100	75
3428.1	17.7	136.5	243.1	4803.3	5.4	340	100	80
3343.6	18.1	145.7	222.2	4988.8	5.4	350	100	80
3259.2	18.5	155.4	201.7	5176.5	5.4	360	100	80
3174.7	18.9	165.4	181.5	5366.4	5.4	370	100	80
3159.9	19.2	175.6	128.0	5400.4	5.4	380	0	0
3159.9	19.4	185.8	74.5	5400.4	5.4	390	0	0
3140.9	19.5	196.0	64.7	5400.4	5.4	400	25	0
3126.1	19.6	206.2	45.4	5400.4	5.4	410	0	0
3117.7	19.7	216.5	11.4	5400.4	5.3	420	25	0
3096.6	19.7	226.7	6.9	5400.4	5.3	430	25	0
3050.1	19.7	236.9	61.6	5400.4	5.3	440	25	0
3029.0	19.9	247.2	57.5	5400.4	5.3	450	25	0
3022.7	19.9	257.4	18.9	5400.4	5.3	460	0	0
3014.2	19.9	267.6	-14.7	5400.4	5.3	470	25	0
2969.9	20.0	277.8	36.3	5400.4	5.3	480	0	0

SIMULATOR OUTPUT #1
LCTV SURFACE TO ORBIT

FMASS (slugs)	YPOS (miles)	XPOS (miles)	VELY (ft/s)	VELX (ft/s)	GRAVITY (ft/s)	TIME (sec)	THRUST (%)	ATTIT (deg
2885.5	20.0	10.1	-13.5	5239.2	5.3	10	100	270
2801.1	19.9	19.8	-67.0	5035.9	5.3	20	100	270
2716.6	19.8	29.2	-120.4	4830.1	5.3	30	100	270
2632.1	19.5	38.1	-173.9	4621.7	5.4	40	100	270
2547.7	19.1	46.7	-227.5	4410.7	5.4	50	100	270
2463.2	18.7	54.8	-207.9	4209.8	5.4	60	100	290
2378.7	18.3	62.6	-187.5	4006.3	5.4	70	100	290
2294.3	18.0	70.0	-177.1	3796.7	5.4	80	100	285
2209.8	17.6	77.0	-173.2	3581.9	5.4	90	100	285
2125.3	17.3	83.6	-168.6	3364.2	5.4	100	100	285
2040.9	17.0	89.7	-163.2	3143.5	5.4	110	100	285
1956.4	16.7	95.5	-153.8	2920.6	5.4	120	100	287
1871.9	16.4	100.8	-154.8	2691.7	5.4	130	100	283
1787.5	16.1	105.7	-155.0	2459.4	5.4	140	100	283
1703.0	15.8	110.1	-154.4	2223.8	5.4	150	100	283
1618.5	15.5	114.1	-153.1	1984.7	5.4	160	100	283
1534.1	15.2	117.6	-151.0	1742.0	5.4	170	100	283
1449.6	15.0	120.7	-148.1	1495.6	5.4	180	100	283
1365.1	14.7	123.3	-144.3	1245.3	5.4	190	100	283
1280.7	14.4	125.4	-139.6	991.2	5.4	200	100	283
1196.2	14.1	127.0	-193.6	726.2	5.4	210	100	270
1124.4	13.7	128.2	-247.7	497.5	5.4	220	25	270
1103.3	13.2	129.1	-301.8	429.6	5.4	230	25	270
1082.2	12.5	129.8	-355.9	361.4	5.4	240	25	270
1061.0	11.8	130.4	-410.2	293.0	5.4	250	25	270
1039.9	11.0	130.9	-450.7	227.9	5.4	260	25	300
1018.8	10.1	131.3	-470.6	168.1	5.4	270	25	300
997.7	9.2	131.5	-490.4	108.1	5.5	280	25	300
976.6	8.3	131.7	-510.2	47.8	5.5	290	25	300
955.5	7.3	131.7	-526.4	-6.5	5.5	300	25	1
934.3	6.3	131.7	-511.0	-5.3	5.5	310	25	1
913.2	5.3	131.7	-495.3	-4.1	5.5	320	25	1
892.1	4.4	131.7	-479.5	-2.8	5.5	330	25	1
871.0	3.5	131.7	-463.5	-1.6	5.5	340	25	1
849.9	2.7	131.7	-447.2	-0.4	5.5	350	25	1
765.4	2.0	131.7	-213.9	-0.4	5.5	360	100	0
725.3	1.8	131.7	-130.3	-0.4	5.5	370	25	0
710.2	1.5	131.7	-133.2	-0.4	5.5	380	1	0
709.4	1.2	131.7	-185.6	-0.4	5.5	390	1	0
708.6	0.8	131.7	-238.0	-0.4	5.5	400	1	0
624.1	0.6	131.7	3.8	-0.4	5.5	410	100	0
617.9	0.6	131.7	-29.6	-0.4	5.5	420	10	0
596.8	0.5	131.7	-9.7	-0.4	5.5	430	25	0
584.1	0.5	131.7	-19.8	-0.4	5.5	440	0	0
584.1	0.4	131.7	-75.2	-0.4	5.5	450	0	0
550.4	0.3	131.7	-9.2	-0.4	5.5	460	100	0
534.7	0.3	131.7	-8.1	-0.4	5.5	470	5	0
530.5	0.2	131.7	-48.3	-0.4	5.5	480	5	0
499.2	0.1	131.7	9.9	-0.4	5.5	490	100	0
493.1	0.1	131.7	-23.0	-0.4	5.5	500	10	0
472.0	0.1	131.7	-1.1	-0.4	5.5	510	25	0
459.3	0.1	131.7	-9.9	-0.4	5.5	520	15	0
446.6	0.0	131.7	-18.6	-0.4	5.5	530	15	0
426.8	0.0	131.7	-0.6	-0.4	5.5	540	100	0

SIMULATOR OUTPUT # 2

LCTV ORBIT TO SURFACE

FMASS (slugs)	YPOS (miles)	XPOS (miles)	VELY (ft/s)	VELX (ft/s)	GRAVITY (ft/s)	TIME (sec)	THRUST (%)	ATTI[illegible] (deg)
6170.7	0.3	0.0	137.5	38.7	5.5	20	100	45
6001.8	1.0	0.5	222.2	234.1	5.5	40	100	45
5832.8	2.0	1.8	287.7	451.9	5.5	60	100	55
5663.9	3.1	4.0	320.2	699.5	5.5	80	100	60
5579.4	4.2	6.9	282.5	825.0	5.5	100	50	60
5495.0	5.3	10.2	275.9	928.3	5.5	120	50	45
5410.5	6.3	13.9	270.4	1032.6	5.5	140	50	45
5326.1	7.4	18.0	266.1	1137.8	5.5	160	50	45
5241.6	8.4	22.5	262.9	1243.9	5.5	180	50	45
5157.1	9.3	27.4	260.9	1351.0	5.5	200	50	45
5072.7	10.3	32.8	260.1	1459.1	5.4	220	50	45
4988.2	11.3	38.5	243.5	1579.1	5.4	240	50	70
4903.7	12.1	44.8	188.2	1725.4	5.4	260	50	70
4819.3	12.7	51.6	133.6	1873.2	5.4	280	50	70
4734.8	13.1	59.0	79.5	2022.4	5.4	300	50	70
4650.3	13.3	66.9	26.1	2173.0	5.4	320	50	70
4565.9	13.4	75.4	27.6	2291.7	5.4	340	50	50
4481.4	13.5	84.3	24.5	2416.9	5.4	360	50	50
4397.0	13.6	93.7	22.4	2543.4	5.4	380	50	50
4312.5	13.7	103.5	21.4	2671.1	5.4	400	50	50
4228.0	13.8	113.9	21.5	2800.1	5.4	420	50	50
4143.6	13.9	124.8	22.7	2930.5	5.4	440	50	50
4059.1	14.0	136.1	25.1	3062.2	5.4	460	50	50
3974.6	14.1	148.0	28.7	3195.2	5.4	480	50	50
3890.2	14.2	160.3	28.8	3333.5	5.4	500	50	53
3805.7	14.3	173.2	27.5	3475.2	5.4	520	50	53
3721.2	14.4	186.7	27.4	3618.4	5.4	540	50	53
3636.8	14.5	200.6	28.5	3763.2	5.4	560	50	53
3552.3	14.6	215.2	30.8	3909.6	5.4	580	50	53
3467.8	14.7	230.3	34.4	4057.7	5.4	600	50	53
3383.4	14.9	245.9	34.0	4211.3	5.4	620	50	55
3298.9	15.0	262.2	34.9	4366.6	5.4	640	50	55
3214.4	15.1	279.0	32.3	4526.9	5.4	660	50	57
3130.0	15.2	296.5	30.1	4689.7	5.4	680	50	57
3045.5	15.3	314.5	29.2	4854.3	5.4	700	50	57
2961.0	15.5	333.2	29.6	5021.0	5.4	720	50	57
2876.6	15.6	352.5	60.7	5165.8	5.4	740	50	45
2792.1	15.8	372.4	17.5	5342.7	5.4	760	50	90
2707.6	15.9	392.9	54.3	5451.5	5.4	780	50	0
2623.2	16.3	413.6	155.3	5451.5	5.4	800	50	0
2538.7	17.1	434.2	259.1	5451.5	5.4	820	50	0
2500.7	18.2	454.9	247.7	5451.5	5.4	840	0	0
2500.7	18.9	475.5	140.5	5451.5	5.4	860	0	0
2498.6	19.2	496.2	38.8	5451.5	5.4	880	25	0
2456.3	19.4	516.8	39.1	5451.5	5.4	900	25	0
2414.1	19.5	537.5	40.1	5451.5	5.4	920	25	0
2371.9	19.7	558.1	41.9	5451.5	5.3	940	25	0
2329.6	19.8	578.8	44.5	5451.5	5.3	960	25	0
2314.0	19.9	599.4	-21.8	5451.5	5.3	980	50	0
2250.7	20.0	620.1	37.3	5451.5	5.3	%1000	0	0
2229.5	20.0	640.7	-13.9	5451.5	5.3	%1020	50	0
2145.1	20.1	661.4	103.9	5451.5	5.3	%1040	50	0

SIMULATOR OUTPUT #3
LCTV ABORT TO ORBIT

FMASS (slugs)	YPOS (miles)	XPOS (miles)	VELY (ft/s)	VELX (ft/s)	GRAVITY (ft/s)	TIME (sec)	THRUST (%)	ATTITU (deg)
6166.1	0.3	0.0	161.1	0.0	5.5	20	100	0
5997.1	1.1	0.3	249.8	185.8	5.5	40	100	45
5828.2	2.2	1.4	320.0	401.3	5.5	60	100	50
5743.7	3.4	3.0	307.6	363.3	5.5	80	50	-45
5659.3	4.5	4.1	284.7	249.6	5.5	100	50	-55
5574.8	5.5	4.9	257.9	130.9	5.5	120	50	-55
5511.5	6.4	5.2	211.1	41.1	5.5	140	25	-55
5480.9	7.1	5.2	132.7	-0.6	5.5	160	2	10
5480.0	7.4	5.2	24.7	-0.4	5.5	180	0	0
5480.0	7.3	5.2	-84.7	-0.4	5.5	200	0	0
5480.0	6.7	5.2	-194.2	-0.4	5.5	220	0	0
5475.8	5.8	5.2	-296.5	-0.4	5.5	240	50	0
5391.3	4.7	5.2	-258.6	-0.4	5.5	260	50	0
5306.9	3.8	5.2	-219.6	-0.4	5.5	280	50	0
5222.4	3.1	5.2	-179.3	-0.4	5.5	300	50	0
5138.0	2.5	5.2	-137.9	-0.4	5.5	320	50	0
5053.5	2.0	5.2	-95.1	-0.4	5.5	340	50	0
4969.0	1.8	5.2	-51.0	-0.4	5.5	360	50	0
4909.9	1.6	5.2	-52.5	-0.4	5.5	380	25	0
4850.8	1.4	5.2	-53.3	-0.4	5.5	400	50	0
4772.6	1.2	5.2	-17.7	-0.4	5.5	420	25	0
4730.4	1.1	5.2	-48.7	-0.4	5.5	440	25	0
4688.2	0.9	5.2	-79.4	-0.4	5.5	460	25	0
4618.5	0.6	5.2	-57.4	-0.4	5.5	480	50	0
4553.0	0.4	5.2	-42.4	-0.4	5.5	500	25	0
4493.9	0.2	5.2	-38.9	-0.4	5.5	520	50	0
4424.2	0.2	5.2	-13.9	-0.4	5.5	540	25	0
4382.0	0.1	5.2	-41.9	-0.4	5.5	560	25	0
4308.1	0.0	5.2	-6.8	-0.4	5.5	580	25	0
4251.1	0.0	5.2	-4.1	-0.4	5.5	600	25	0
4196.2	0.0	5.2	-4.9	-0.4	5.5	620	25	0

SIMULATOR OUTPUT#4
LCTV ABORT TO SURFACE

COST ANALYSIS

Design and Development

I Structure
1. System layout
2. Finite element analysis of structural panels
3. Manufacturing
   a. Material
   b. Machining of panels
   c. Assembly of panels and beams

II Propulsion and Power System
1. 30,000 lb. LH/LOX Rocket Engines
   a. Design
   b. Testing
   c. Manufacturing
2. RCS system
   a. Apllication of system to LCTV
   b. Manufacturing
3. Hydraulic actuators
   a. Design
   b. Manufacturing
4. Fuel cells
   a. Selection and purchasing
5. Fuel delivery system (all purchasing costs)
   a. Lines
   b. Valve assemblies
   c. Pressure fittings
   d. Insulation
   e. Mounting hardware
   f. Assembly

III MPS and RCS Tanks
1. Elastomer bladders
2. Testing
3. Manufacturing

IV Payload and Payload Exchange System
1. Pallet
   a. Purchasing
   b. Development of modifications
   c. Implementation of modifications
   d. Testing
2. Containers
   a. Design
   b. Manufacturing
3. Payload Exchange and Refueling Unit
   a. Development
   b. Testing
   c. Manufacturing

V Landing Gear
1. Market survey
2. Application adaptation
3. Testing
4. Manufacturing

VI Control System
1. Main mission controller
   a. Hardware
   b. Software
   c. System integration and testing
2. Navigation/Guidance system
   a. Hardware
   b. Software
   c. System integration and testing
3. Communications
   a. Hardware
   b. Software
   c. System integration and testing
4. Main propulsion controller
   a. Hardware
   b. Software
   c. System integration and testing
5. Payload Handling Controller
   a. Hardware
   b. Software
   c. System integration and testing

Operational

I Structure
1. No routine maintanence

II Propulsion and Power System
1. Required every flight
   a. Helium pressurant
   b. RCS and MPS system inspection
   c. Fuel and oxidizor
2. Maintanence
   a. Vornior thruster replacement (approx. every 20 flights)
   b. Primary thruster replacement (approx. every 100 flights)
   c. MPS component replacement (as required)
   d. Hydraulic System fluid replacement (as required)

III Main Propulsion System Tanks
1. Elastomer bladders replacement (approx every 100 flights)
2. Repair of tanks

IV Payload and Payload Exchange System
1. Maintanence as required
   a. Hydraulic system
   b. Gears and motor
   c. Bearings
   d. Docking locks
   e. Refueling nozzles

V Landing Gear
1. Maintanence
2. Replacement (as required)

VI Control System
1. Main mission controller
   a. Software updates
   b. Hardware maintanence
2. Navigation/Guidance system
   a. Software updates
   b. Hardware maintanence
3. Communications
   a. Software updates
   b. Hardware maintanence
4. Main propulsion controller
   a. Software updates
   b. Hardware maintanence
5. Payload handling controller
   a. Software updates
   b. Hardware maintanence

FUTURE DEVELOPMENTS

An additional use for the LCTV could be as a transport vehicle between lunar bases. Using the current design, the LCTV would have a very limited range, roughly 75 miles (120.75 km). Calculations indicate that if the present MPS engines were replaced with 15,000 lbf (66,750N) engines, the fuel/oxidizer tanks downsized, and the payload exchange unit removed, the LCTV could be used as a transort between lunar bases.

Main Propulsion System

In order for the LCTV to be economical, one of two things must occur. Either lunar production of both fuel and oxidizer must become possible or a new engine technology must be developed. Liquid chemical rockets are to the pointin their design that any changes in them will only result in a very small improvement in efficiency. Therefore, a new type of engine must be developed. The best choice for the new technology would be nuclear rockets, but the social and political attitudes toward these engines must improve before they can be developed.

Propellant Tanks

At the present time, the large fuel tanks are proven to be structurally sound, relatively light weight, and easy to manufacture from aluminum alloys. The future developments on these tanks will be limited to optimization of present designs. The polymer bladders may be improved by using new compounds to prolong their life while in contact with the propellants. The use of fiber glass tanks with aluminum liners is possible if their inherent problems with extremely low temperatures can be solved.

Payload and Payload Exchange

In order to optimize the efficiency of the LCTV and OTV, two studies should be done. These are to decide if a refueling and docking station should be located in orbit and if it is more economical for the OTV to carry the Payload Exchange Refueling Unit. With these two studies, an optimum mode of payload transfer can be chosen.

Other improvements would be to make the PERU a structure instead of machined out of aluminum stock. This was not taken into consideration in the earlier section on the PERU because the weight of the present PERU is small compared to the entire LCTV. It should be decided if this savings of weight is worth the added cost of development.

The six hydraulic cylinders used to latch the cargo will be costly to mantain, therefore another method of latching should be developed.

Controls

The major change in controls will be keeping all the systems up to date with the state of the art. As computers get smaller, faster, and cheaper, better control systems can be designed to optimize the flight and save fuel. Alse these newer systems will weigh less and take up less room, allowing for more redundancies. Also it may be possible to incorporate artificial intelligence into the MMC so that after each flight, the MMC will be able to remember any changes in the flight it had to make and use these changes for the next flight.

LCTV
Group 13
January 27, 1986

Title:
The Design and Implementation of a Lunar Surface to Lunar Orbit Cargo Transport Space Vehicle

Propulsion:
Three basic forms of propulsive systems were studied for use on the space vehicle. Electric rockets, including ion rockets and MPD thrusters, had the advantages of long life, low fuel consumption, and a high specific impulse. There were decided disadvantages though, due to low thrust force, high weight, low accelerations, and system complications. Nuclear rockets had good thrust force, good acceleration, and low fuel consumption, but were hurt by radiation problems, complicated control systems, and present technological development. Finally, liquid chemical rockets have high thrust, high acceleration, proven control systems and technology. Problems with these rockets were due to high fuel consumption, explosion problems, and low specific impulse. Analysis of this data led to the conclusion that with present technology the only viable alternative was the use of liquid chemical rockets. Further analysis of these rockets was then begun.

Controls:
After reviewing the proposed latching mechanisms, investigation of systems to line up the cargo package with the landing vehicle while in orbit was begun. Various systems were investigated including using lasers, microwaves, or vision systems. Initial lining up of the vehicles will most likely be accomplished by microwave radar systems with possibly another system taking over as the vehicles near each other.

Structures/Mechanisms
Various methods of latching onto and releasing the cargo package in space were discussed. The design of the carge configuration was finalized as separate pods attached to a platform which kept are together throughout the entire process. Some members began training on the IBM CADAM graphics system.

LCTV
Group 13
Date due Februray 3, 1986

CONTROLS- Continued investigation of control systems of various aerospace vehicles, including the B-1 Bomber and the Lunar Lander. Divided control systems into five basic units: propulsion, navigation, test and error recovery, power generation system, and cargo handling. Each system will have it's own microprocessor tied into a main control system through a single wire emux-system. The main control system will consist of 3 or 5 different computers, each running the same program, for constant error checking, as used on the shuttle.

STRUCTURES- Investigated methods of attaching rocket engines to aerospace structures. After considering various methods of unloading and retrieving cargo, arrived at preliminary concept of a lunar orbiting station. This station would be a refueling point for our lander and a cargo mooring. While the station requires the addition of a structure and another control system, the advantages of this concept may out-weigh this disadvantage. The advantages are as follows:

1) Less fuel consumption because fuel is not carried to the moon as payload.
2) One point where our lander can be refueled and drop off and retrieve cargo.
3) One point where the O.T.V. can drop off fuel and cargo and retrieve cargo.
4) Attachment of our lander and the cargo package can be handled mechanically by the fuel station for a more reliable, safe and direct linkage.
5) O.T.V. and Lander do not have to meet at the same time.

ORBITAL MECHANICS- Currently converting Astrodynamics program, furnished by NASA, from HP-65 machine code to HP-41C/CX machine code.

PROPULSION SYSTEMS- Currently investigating five engine cluster assembly. Center engine is fixed and four surrounding engines are gimbled. Research for a rocket engine from existing technology is in progress.

[illegible], 198[illegible]

[illegible] analysis of existing chemical rockets indicates [illegible] possibilities in the 20,000 lb. to 50,000 lb. thrust range. Final evaluations have led to limiting our search to LOX/LH and LOX/kerosene engines. These class engines are very [illegible] space vehicles. Initial piping diagrams [illegible] [illegible] analysis of these will begin [illegible] [illegible] down. Flight profiles [illegible] fuel consumption simulation.

[illegible]

[illegible] of the individual systems, mainly the propulsion [illegible] has been started. This includes defining [illegible] shut-down sequence, and change of thrust. The [illegible] computer will only issue three commands to the [illegible] computer. The propulsion computer will then [illegible] and/or [illegible] the appropriated valves and receive data from engine sensors. This hierarchy allows the main control computer to [illegible] mode and never actually control any hardware, [illegible] for easier error recovery.

[illegible]

[illegible]: The use of an existing pallet used in previous [illegible] flights will require modifications for payload exchange [illegible] [illegible] and OTV.

[illegible]: The payload exchange will be performed by [illegible] controlled by its own [illegible] [illegible] will latch onto each of the pallets [illegible]. A refueling system will also be a part of [illegible]. It is suggested that this will be [illegible] OTV does not have to carry it through [illegible].

[illegible]

[illegible] of investigating different methods [illegible] for the rockets throughout the [illegible] method of gimbaling engines.

ORIGINAL PAGE IS
OF POOR QUALITY

LCTV
Group 13
Feb. 17, 1986

Controls:
We have begun investigation of guidance and navigation systems. Since total flight time will be less than 10 minutes, an internal guidance system will be used to place the vehicle in orbit. The guidance computer will be pre-loaded with the mission profile program which will describe the flight necessary to obtain orbit. Once in the vicinity of the OTV, a laser tracking system will be used to dock the vehicles. Several EE professors have information on these laser tracking systems.

Payload:
We are performing stress analysis on the Payload Exchange Unit to determine dimensions and exchange time. In addition we are investigating methods of arm latching onto the pallet. We are also presently sketching illustrations to explain the payload exchange process.

Propulsion:
Final design considerations were made on the main propulsion engines.

Number of engines: 4
Type of engine: Hypothetical engine based on technology developed by Pratt and Whitney.
Thrust per engine: 30,000 lb.
Fuel: Liquid Hydrogen
Oxidizer: Liquid Oxygen

Additionally final analysis was begun on the gimbal linear actuator attitude control system. The Space Shuttle reaction control system was chosen as the basis for control rockets. Initial investigation of fuel cells to provide onboard power was begun.

Fuel Tanks:
The preliminary design of the tanks, given the amount of fuel needed for a mission and the basic structure of the vehicle, shows that cylindrical tanks will be used. The tanks (2 for hydrogen and 1 for oxygen) will have to be cooled to keep the fuel from boiling. In addition, 2 small spherical tanks will be used to house the fuels for the control rockets.

Structures:
Now that the other systems design has been finalized, the structure can begin to be developed to house and support the other systems. After scanning through aerospace structures books in the library, we developed a concept of a structure that is shaped like an elongated, inverted, truncated pyramid.

LCTV
Group 13
February 24, 1986

Propulsion:
The final specifications for all primary equipment have been completed. The flight simulation program has provided sufficient data to calculate fuel and oxidizer requirements. Information from the structural engineer has allowed a choice of control thruster systems and required fuel loads. this system has been closely modeled after the Space Shuttle system. the gimbal actuator system, using hydraulically operated pistons, has been specified. Final quantities of electric fuel cells will be specified as soon as power loads are available. The computer simulation will be used to demonstrate abort-to-orbit, abort-to-surface and surface-to-surface flights.

Payload:
Finalizing drawings for payload exchange unit and will attempt to put them on CADAM. Finishing illustrative drawings and prepaing to begin written report. Also devising method of latching payload exchange unit arm to pallet.

Controls:
Finalized system and sub-system control specifications. Using information from the propulsion engineer and the computer simulation, started defining flight dynamics and how each portion of the flight will be controlled, including how to recover from various failures. Also started searching for commercial sub-systems that could be used in the vehicle.

LCTV
Group 13
March 3, 1986

All the final design variables have been set. Final rough drafts of report sections were submitted for committee review. Critical analysis was performed on all the papers. All drawings are in some stage of development. By the end of next week, all drafts and drawings are to be completed.

List of proposed drawings:

Main Propulsion System Engine Schematic
Main Propulsion System Piping Schematic
Structural Drawings
Fuel System Tank Drawings
Control System Schematics
Payload Exchange System Drawings

LCTV
Group 13
March 10, 1986

All final drafts and drawings have been completed. A final group meeting was held to perform a final critical analysis of the report. All parts of the report were compiled and copies are being made for all members of the group as well as the copy to be submitted.

One spokesman was chosen to deliver the presentation on March 11, 1986.

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